# Mathematics Manual
for

# WATER AND WASTEWATER TREATMENT PLANT OPERATORS

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# PREFACE

To properly operate a waterworks or wastewater treatment plant and to pass the examination for a waterworks/wastewater operator's license, it is necessary to know how to perform certain calculations. In reality, most of the calculations that operators at the lower level of licensure need to know how to perform are not difficult, but all operators need a basic understanding of arithmetic and problem-solving techniques to be able to solve the problems they typically encounter.

How about waterworks/wastewater treatment plant operators at higher levels of licensure — do they also need to be well versed in mathematical operations? The short answer is absolutely. The long answer is that anyone who works in water or wastewater treatment and who expects to have a successful career that includes advancement to the highest levels of licensure or certification (usually prerequisites for advancement to higher management levels) must have knowledge of math at both the basic or fundamental level and at the advanced practical level. It is simply not possible to succeed in this field without the ability to perform mathematical operations.

Keep in mind that mathematics is a universal language. Mathematical symbols have the same meaning to people speaking many different languages throughout the world. The key to using mathematics is learning the language, symbols, definitions, and terms of mathematics that allow us to grasp the concepts necessary to solve equations.

In *Mathematics Manual for Water/Wastewater Treatment Plant Operators*, we begin by introducing and reviewing concepts critical to the qualified operators at the fundamental or entry level; however, this does not mean that these are the only math concepts that a competent operator must know to solve routine operation and maintenance problems. After covering the basics, therefore, the text progressively advances, step-by-step, to higher more practical applications of mathematical calculations — that is, the math operations that operators at the highest level of licensure would be expected to know how to perform.

The basic level reviews fractions and decimals, rounding numbers, determining the correct number of significant digits, raising numbers to powers, averages, proportions, conversion factors, calculating flow and detention times, and determining the areas and volumes of different shapes. This review also explains how to keep track of units of measurement (inches, feet, gallons, etc.) during calculations and demonstrates how to solve real-life problems that require calculations.

After building a strong foundation based on theoretical math concepts (the basic tools of mathematics, such as fractions, decimals, percents, areas, volumes), we move on to applied math — basic math concepts applied when solving practical water/wastewater operational problems. Even though considerable crossover of basic math operations used by both waterworks and wastewater operators occurs, this book separates applied math problems for wastewater and water to aid operators dealing with specific unit processes unique to either waterworks or wastewater operations.

The text is divided into five parts. Part I covers basic math concepts used in both water and wastewater treatment. Part II covers advanced math concepts for waterworks operators. Part III covers advanced math concepts for wastewater operators. Part IV covers fundamental laboratory calculations used in both water and wastewater treatment operations. Part V presents a comprehensive workbook of more than 1400 practical math problems that highlight the type of math exam questions operators can expect to see on state licensure examinations.

What makes *Mathematics Manual for Water/Wastewater Treatment Plant Operators* different from other math books available? Consider the following:

- The author has worked in and around water/wastewater treatment and taught water/wastewater math for several years.
- The author has sat at the table of licensure examination preparation boards to review, edit, and write state licensure exams.
- This step-by-step training manual provides concise, practical instruction in the math skills that operators must have to pass certification tests.
- The text is completely self-contained in one complete volume. The advantage should be obvious — one text that combines math basics and advanced operator math concepts eliminates shuffling from one volume to another to find the solution to a simple or more complex problem.
- The text is user friendly; no matter the difficulty of the problem to be solved, each operation is explained in straightforward, plain English. Moreover, numerous example problems (several hundred) are presented to enhance the learning process.

To assure correlation to modern practice and design, the text provides illustrative problems dealing with commonly encountered waterworks/wastewater treatment operations and associated parameters and covers typical math concepts for waterworks/wastewater treatment unit process operations found in today's waterworks/wastewater treatment facilities.

✔ ***Note:*** The symbol ✔ displayed in various locations throughout this manual indicates or emphasizes an important point or points to study carefully.

This text is accessible to those who have little or no experience in treatment plant math operations. Readers who work through the text systematically will be surprised at how easily they can acquire an understanding of water/wastewater math concepts, thus adding another critical component to their professional knowledge.

A final point before beginning our discussion of math concepts: It can be said with some accuracy and certainty that without the ability to work basic math problems (i.e., those typical to water/wastewater treatment) candidates for licensure will find any attempts to successfully pass licensure exams a much more difficult proposition.

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# Part I

## Basic Math Concepts

# 1 Introduction

## TOPICS

- Math Terminology and Definitions
- Calculators

Anyone who has had the opportunity to work in waterworks and/or wastewater treatment, even for a short time, learns quickly that water/wastewater treatment operations involve a large number of process control calculations. All of these calculations are based upon basic math principles. In this chapter, we introduce basic mathematical terminology and definitions and calculator operations that water/wastewater operators are required to use, many of them on a daily basis.

What is *mathematics*? Good question. Mathematics is numbers and symbols. Math uses combinations of numbers and symbols to solve practical problems. Every day, we use numbers to count. Numbers may be considered as representing things counted. The money in your pocket or the power consumed by an electric motor is expressed in numbers. When operators make entries in the Plant Daily Operating Log, they enter numbers in parameter columns, indicating the operational status of various unit processes — many of these math entries are required by the NPDES permit for the plant. Again, we use numbers every day. Because we use numbers every day, we are all mathematicians — to a point.

In water/wastewater treatment, we need to take math beyond "to a point". We need to learn, understand, appreciate, and use mathematics. Not knowing the key definitions of the terms used is probably the greatest single cause of failure to understand and appreciate mathematics.. In mathematics, more than in any other subject, each word used has a definite and fixed meaning. The math terminology and definitions section will aid in understanding the material in this book.

## MATH TERMINOLOGY AND DEFINITIONS

- An *integer*, or an *integral number*, is a whole number; thus 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12 are the first 12 positive integers.
- A *factor*, or *divisor*, of a whole number is any other whole number that exactly divides it. Thus, 2 and 5 are factors of 10.
- A *prime number* in math is a number that has no factors except itself and 1. Examples of prime numbers are 1, 3, 5, 7, and 11.
- A *composite number* is a number that has factors other than itself and 1. Examples of composite numbers are 4, 6, 8, 9, and 12.
- A *common factor*, or *common divisor*, of two or more numbers is a factor that will exactly divide each of them. If this factor is the largest factor possible, it is called the *greatest common divisor*. Thus, 3 is a common divisor of 9 and 27, but 9 is the greatest common divisor of 9 and 27.
- A *multiple* of a given number is a number that is exactly divisible by the given number. If a number is exactly divisible by two or more other numbers, it is a common multiple of them. The least (smallest) such number is called the *lowest common multiple*. Thus, 36 and 72 are common multiples of 12, 9, and 4; however, 36 is the lowest common multiple.

- An *even number* is a number exactly divisible by 2; thus, 2, 4, 6, 8, 10, and 12 are even integers.
- An *odd number* is an integer that is not exactly divisible by 2; thus, 1, 3, 5, 7, 9, and 11 are odd integers.
- A *product* is the result of multiplying two or more numbers together; thus, 25 is the product of $5 \times 5$. Also, 4 and 5 are factors of 20.
- A *quotient* is the result of dividing one number by another; for example, 5 is the quotient of 20 divided by 4.
- A *dividend* is a number to be divided, and a *divisor* is a number that divides; for example, in $100 \div 20 = 5$, the dividend is 100, the divisor is 20, and the quotient is 5.
- *Area* is the area of an object, measured in square units
- *Base* is a term used to identify the bottom leg of a triangle, measured in linear units.
- *Circumference* is the distance around an object, measured in linear units. When determined for a shape other than a circle, it may be called the *perimeter* of the figure, object, or landscape.
- *Cubic units* are measurements used to express volume, cubic feet, cubic meters, etc.
- *Depth* is the vertical distance from the bottom of the tank to the top. This is normally measured in terms of liquid depth and given in terms of sidewall depth (SWD), measured in linear units.
- *Diameter* is the distance from one edge of a circle to the opposite edge passing through the center, measured in linear units.
- *Height* is the vertical distance from the base or bottom of a unit to the top or surface.
- *Linear units* are measurements used to express distances (e.g., feet, inches, meters, yards).
- *Pi* ($\pi$) is a number used in calculations involving circles, spheres, or cones; $\pi = 3.14$.
- *Radius* is the distance from the center of a circle to the edge, measured in linear units.
- *Sphere* is a container shaped like a ball.
- *Square units* are measurements used to express area, square feet, square meters, acres, etc.
- *Volume* is the capacity of the unit (how much it will hold) measured in cubic units (cubic feet, cubic meters) or in liquid volume units (gallons, liters, million gallons).
- *Width* is the distance from one side of the tank to the other, measured in linear units.

## Calculation Steps

Standard methodology used in making mathematical calculations includes:

- Making a drawing of the information in the problem, if appropriate.
- Placing the given data on the drawing.
- Asking, "What is the question?" This is the first thing you should ask along with, "What are they really looking for?"
- Writing it down, if the calculation calls for an equation.
- Filling in the data in the equation — look to see what is missing.
- Rearranging or transposing the equation, if necessary.
- Using a calculator, if available.
- Writing down the answer, always.
- Checking any solution obtained. Does the answer make sense?

✓ **Important Point:** Solving word math problems is difficult for many operators. Solving these problems is made easier, however, by understanding a few key words.

### Key Words

- The term *of* means to multiply
- The term *and* means to add
- The term *per* means to divide
- The term *less than* means to subtract

## CALCULATORS

You have heard the old saying, "Use it or lose it." This saying amply applies to mathematics. Consider the person who first learns to perform long division, multiplication, square root, adding and subtracting, converting decimals to fractions, and other math operations using nothing more than pencil and paper and brain power. Eventually, this same person is handed a pocket calculator that can produce all of these functions and much more simply by manipulating certain keys on a keyboard. This process involves little brainpower — nothing more than punching in correct numbers and operations to achieve an almost instant answer. Backspacing to the previous statement ("use it or lose it") makes our point. As with other learned skills, our proficiency in performing a learned skill is directly proportionate to the amount of time we spend using the skill — whatever that might be. We either use it or we lose it. The consistent use of calculators has caused many of us to forget how to perform basic math operations with pencil and paper — for example, how to perform long division.

Without a doubt, the proper use of a calculator can reduce the time and effort required to perform calculations; thus, it is important to recognize the calculator as a helpful tool, with the help of a well-illustrated instruction manual, of course. The manual should be large enough to read, not an inch by an inch by a quarter of an inch in size. It should have examples of problems and answers with illustrations. Careful review of the instructions and practice using example problems are the best ways to learn how to use the calculator.

Keep in mind that the calculator you select should be large enough so that you can use it. Many of the modern calculators have keys so small that it is almost impossible to hit just one key. You will be doing a considerable amount of work during this study effort — make it as easy on yourself as you can.

Another significant point to keep in mind when selecting a calculator is the importance of purchasing a unit that has the functions you need. Although a calculator with a lot of functions may look impressive, it can be complicated to use. Generally, the water/wastewater plant operator requires a calculator that can add, subtract, multiply, and divide. A calculator with a parentheses function is helpful, and, if you must calculate geometric means for fecal coliform reporting, for example, then logarithmic capability is also helpful.

In many cases, calculators can be used to perform several mathematical functions in succession. Because various calculators are designed using different operating systems, you must review the instructions carefully to determine how to make the best use of the system.

Finally, it is important to keep a couple of basic rules in mind when performing calculations:

- Always write down the calculations you wish to perform
- Remove any parentheses or brackets by performing the calculations inside first

# 2 Sequence of Operations

## TOPICS



Mathematical operations such as addition, subtraction, multiplication, and division are usually performed in a certain order or sequence. Typically, multiplication and division operations are done prior to addition and subtraction operations. In addition, mathematical operations are also generally performed from left to right using this hierarchy. The use of parentheses is also common to set apart operations that should be performed in a particular sequence.

✔ **Note:** It is assumed that the reader has a fundamental knowledge of basic arithmetic and math operations. Thus, the purpose of the following section is to provide only a brief review of the mathematical concepts and applications frequently employed by water/wastewater operators.

## SEQUENCE OF OPERATIONS — RULES

**Rule 1:** In a series of *additions*, the terms may be placed in any order and grouped in any way; thus, 4 + 3 = 7 and 3 + 4 = 7; (4 + 3) + (6 + 4) = 17, (6 + 3) + (4 + 4) = 17, and [6 + (3 + 4) + 4] = 17.

**Rule 2:** In a series of *subtractions*, changing the order or the grouping of the terms may change the result; thus, 100 – 30 = 70, but 30 –100 = –70; (100 – 30) – 10 = 60, but 100 – (30 – 10) = 80.

**Rule 3:** When no grouping is given, the subtractions are performed in the order written from left to right (e.g., 100 – 30 – 15 – 4 = 51) or by steps, (e.g., 100 – 30 = 70, 70 – 15 = 55, 55 – 4 = 51).

**Rule 4:** In a series of *multiplications*, the factors may be placed in any order and in any grouping; thus, [(2 × 3) × 5] × 6 = 180 and 5 × [2 × (6 × 3)] = 180.

**Rule 5:** In a series of *divisions*, changing the order or the grouping may change the result; thus, 100 ÷ 10 = 10 but 10 ÷ 100 = 0.1 and (100 ÷ 10) ÷ 2 = 5 but 100 ÷ (10 ÷ 2) = 20. Again, if no grouping is indicated, the divisions are performed in the order written from left to right; thus, 100 ÷ 10 ÷ 2 is understood to mean (100 ÷ 10) ÷ 2.

**Rule 6:** In a series of mixed mathematical operations, the convention is as follows: Whenever no grouping is given, multiplications and divisions are to be performed in the order written, then additions and subtractions in the order written.

## SEQUENCE OF OPERATIONS — EXAMPLES

- In a series of additions, the terms may be placed in any order and grouped in any way.

### Examples

$3 + 6 = 10$ and $6 + 4 = 10$
$(4 + 5) + (3 + 7) = 19$, $(3 + 5) + (4 + 7) = 19$, and $[7 + (5 + 4)] + 3 = 19$

- In a series of subtractions, changing the order or the grouping of the terms may change the result.

### Examples

$100 - 20 = 80$, but $20 - 100 = -80$
$(100 - 30) - 20 = 50$, but $100 - (30 - 20) = 90$

- When no grouping is given, the subtractions are performed in the order written — from left to right.

### Examples

$100 - 30 - 20 - 3 = 47$
or by steps, $100 - 30 = 70$, $70 - 20 = 50$, $50 - 3 = 47$

- In a series of multiplications, the factors may be placed in any order and in any grouping.

### Examples

$[(3 \times 3) \times 5] \times 6 = 270$ and $5 \times [3 \times (6 \times 3)] = 270$

- In a series of divisions, changing the order or the grouping may change the result.

### Examples

$100 \div 10 = 10$, but $10 \div 100 = 0.1$
$(100 \div 10) \div 2 = 5$, but $100 \div (10 \div 2) = 20$

- If no grouping is indicated, the divisions are performed in the order written — from left to right.

### Examples

$100 \div 5 \div 2$ is understood to mean $(100 \div 5) \div 2$

- In a series of mixed mathematical operations, the rule of thumb is that, whenever no grouping is given, multiplications and divisions are to be performed in the order written, then additions and subtractions in the order written.

### Example 2.1

*Problem*

Perform the following mathematical operations to solve for the correct answer:

$$(2+4)+(2\times 6)+\left(\frac{6+2}{2}\right)= \underline{\hspace{3cm}}$$

*Solution*

- Mathematical operations are typically performed going from left to right within an equation and within sets of parentheses.
- Perform all math operations within the sets of parentheses first:

$$2 + 4 = 6$$

$$2 \times 6 = 12$$

$$\frac{6+2}{2} = \frac{8}{2} = 4$$

  (Note that the addition of 6 and 2 was performed prior to dividing.)
- Perform all math operations outside of the parentheses. In this case, from left to right.

$$6 + 12 + 4 = 22$$

**Example 2.2**

*Problem*

Solve the following equation:

$$(4 - 2) + (3 \times 3) - (15 \div 3) - 8 = \underline{\qquad\qquad}$$

*Solution*

- Perform math operations inside each set of parentheses:

$$4 - 2 = 2$$

$$3 \times 3 = 9$$

$$15 \div 3 = 5$$

- Perform addition and subtraction operations from left to right.
- The final answer is $2 + 9 - 5 - 8 = -2$.

There may be cases where several operations will be performed within multiple sets of parentheses. In these cases, we must perform all operations within the innermost set of parentheses first and move outward. We must continue to observe the hierarchical rules throughout the problem. Brackets [ ] may indicate additional sets of parentheses.

**Example 2.3**

*Problem*

Solve the following equation:

$$[2 \times (3 + 5) - 5 + 2] \times 3 = \underline{\qquad\qquad}$$

*Solution*

- Perform operations in the innermost set of parentheses.

$$3 + 5 = 8$$

- Rewrite the equation.

$$[2 \times 8 - 5 + 2] \times 3 =$$

- Perform multiplication prior to addition and subtraction within the bracket.

$$[16 - 5 + 2] \times 3 =$$

$$[11 + 2] \times 3 =$$

$$[13] \times 3 =$$

- Perform multiplication outside the brackets.

$$13 \times 3 = 39$$

**Example 2.4**

*Problem*
Solve the following equation:

$$7 + [2\ (3 + 1) - 1] \times 2 = \underline{\qquad\qquad}$$

*Solution*

$$7 + [2\ (4) - 1] \times 2 =$$

$$7 + [8 - 1] \times 2 =$$

$$7 + [7] \times 2 =$$

$$7 + 14 = 21$$

**Example 2.5**

*Problem*
Solve the following equation:

$$[(12 - 4) \div 2] + [4 \times (5 - 3)] = \underline{\qquad\qquad}$$

*Solution*

$$[(8) \div 2] + [4 \times (2)] =$$

$$[4] + [8] =$$

$$4 + 8 = 12$$

# 3 Fractions, Decimals, and Percent

## TOPICS



The number 10 divided by 2 gives an exact quotient of 5. This may be written as 10/2 = 5. However, if we attempt to divide 7 by 9, we are unable to calculate an exact quotient. This division may be written 7/9 (read "seven ninths"). The number 7/9 represents a number, but not a whole number, and is called a *fraction.* Simply put, fractions are used to express a portion of a whole.

The water/waterworks operator is often faced with routine situations that require thinking in fractions and, on occasion, actually working with fractions. One of the common rules governing the use of fractions in a math problem deals with units of the problem. Units such as gpm are actually fractions — (gallons per minute or gal/min). Another example is — cubic feet per second (cfs), which is actually $ft^3$/sec. As can be seen, understanding fractions helps in solving other problems.

A fraction is composed of three items: two numbers and a line. The number on the top is called the *numerator*, the number on the bottom is called the *denominator*, and the line in between them means divided.

$$\text{Divide}\,\frac{3 \leftarrow \text{Numerator}}{4 \leftarrow \text{Denominator}}$$

The denominator indicates the number of equal-sized pieces into which the entire entity has been cut, and the numerator indicates how many pieces we have.

## FRACTIONS

In solving fractions, the following key points are important:

- Fractions are used to express a portion of a whole
- A fraction consists of two numbers separated by a horizontal line or a diagonal line — for example, 1/6
- The bottom number, called the *denominator*, indicates the number of equal-sized pieces into which the entire entity has been cut
- The top number, called the *numerator*, indicates the number of pieces
- Like all other math functions, dealing with fractions is governed by rules or principles

Principles associated with using fractions include:

- *Same numerator and denominator:* When the numerator and denominator of a fraction are the same, the fraction can be reduced to 1; for example, 5/5 = 1, 33/33 = 1, 69/69 = 1, 34.5/34.5 = 1, 12/12 = 1.

- *Whole numbers to fractions:* Any whole number can be expressed as a fraction by placing a 1 in the denominator; for example, 3 is the same as 3/1 and 69 is the same as 69/1.
- *Adding fractions:* Only fractions with the same denominator can be added, and only the numerators are added; the denominator stays the same — for example, 1/9 + 3/9 = 4/9 and 6/18 + 8/18 = 14/18.
- *Subtracting fractions:* Only fractions with the same denominator can be subtracted, and only the numerators are subtracted; the denominator remains the same — for example, 7/9 – 4/9 = 3/9 (reduced = 1/3) and 16/30 – 12/30 = 4/30.
- *Mixed numbers:* A fraction combined with a whole number is called a mixed number — for example, $4^1/_3$, $14^2/_3$, $6^5/_7$, $43^1/_2$, and $23^{12}/_{35}$. The numbers are read "four and one third", "fourteen and two thirds", "six and five sevenths", "forty three and one half", and "twenty three and twelve thirty fifths".
- *Changing a fraction:* Multiplying the numerator and the denominator by the same number does not change the value of the fraction. For example, 1/3 is the same as $(1 \times 3)/(3 \times 3)$ which is 3/9.
- *Simplest terms:* Fractions should be reduced to their simplest terms. This is accomplished by dividing the numerator and denominator by the same number. The result of this division must leave both the numerator and the denominator as whole numbers. For example, 2/6 is not in its simplest terms; by dividing both by 2 we obtain 1/3. The number 2/3 cannot be reduced any further as no number can be divided evenly into both the 2 and the 3.

### Example 3.1

*Problems*

Reduce the following to their simplest terms:

2/4 = ________________
14/18 = ________________
3/4 = ________________
6/10 = ________________
9/18 = ________________
17/29 = ________________
24/32 = ________________

*Solutions*

2/4 = 1/2 (both were divided by 2)
14/18 = 7/9 (both were divided by 2)
3/4 = 3/4 (is in its simplest terms)
6/10 = 3/5 (both were divided by 2)
9/18 = 1/2 (both were divided by 9)
17/29 = 17/29 (is in its simplest form)
24/32 = 3/4 (both were divided by 8)

- *Reducing even numbers:* When the starting point is not obvious, do the following: If the numerator and denominator are both even numbers (2, 4, 6, 8, 10, etc.), divide them both by 2, continue dividing by 2 until a division will no longer yield a whole-number numerator and denominator.

- *Reducing odd numbers:* When the numerator and denominator are both odd numbers, (3, 5, 7, 9, 11, 13, 15, 17, etc.), attempt to divide by 3 and continue dividing by 3 until a division will no longer yield a whole-number numerator and denominator. It is obvious that some numbers such as 5, 7, and 11 cannot be divided by 3 and may in fact be in their simplest terms.
- *Different denominators:* To add and/or subtract fractions with different denominators, the denominators must be changed to a common denominator (the denominators must be the same). Each fraction must then be converted to a fraction expressing the new denominator. For example, to add 1/8 and 2/5:
  - Begin by multiplying the denominators: $8 \times 5 = 40$.
  - Change 1/8 to a fraction with 40 as the denominator: 40/8 = 5, $5 \times 1 = 5$ (the numerator); new fraction is 5/40. Notice that this is the same as 1/8 except that 5/40 is not reduced to its simplest terms.
  - Change 2/5 to a fraction with 40 as the denominator: $40 \div 5 = 8$, $8 \times 2 = 16$ (the numerator); new fraction is 16/40.
  - Complete the addition: 5/40 + 16/40 = 21/40.
- *Numerator larger:* Any time the numerator is larger than the denominator, the fraction should be turned into a mixed number. This is accomplished by doing the following:
  - Determine the number of times the denominator can be divided evenly into the numerator. This will be the whole number portion of the mixed number.
  - Multiply the whole number times the denominator and subtract from the numerator; this value (the remainder) becomes the numerator of the fraction portion of the mixed number. For example, for 28/12, 28 is divisible by 12 twice, so 2 is the whole number. Then, $2 \times 12 = 24$, and 28/12 – 24/12 = 4/12. Dividing the top and bottom by 4 gives us 1/3. The new mixed number is $2^1/_3$.
- *Multiplying fractions:* In order to multiply fractions, simply multiply the denominators together, and reduce to the simplest terms. For instance, to find the result of multiplying $1/8 \times 2/3$:

$$\frac{1}{8} \times \frac{2}{3} = \frac{1 \times 2 = 2}{8 \times 3 = 24} = \frac{2}{24} = \frac{1}{12}$$

- *Dividing fractions:* In order to divide fractions, simply invert the denominator (turn it upside down), multiply, and reduce to simplest terms. For example, to divide 1/9 by 2/3:

$$\frac{\frac{1}{9}}{\frac{2}{3}} = \frac{1}{9} \times \frac{3}{2} = \frac{1 \times 3 = 3}{9 \times 2 = 18} = \frac{3}{18}, \text{ reduced} = \frac{1}{6}$$

**Important Point:** The divide symbol can be (÷) or (/) or (—).

- *Fractions to decimals:* In order to convert a fraction to a decimal, simply divide the numerator by the denominator; for example:

1/2 = 0.5, 5/8 = 0.625, 7/16 = 0.4375, 1/4 = 0.25

- *Change inches to feet:* To change inches to feet, divide the number of inches by 12; for example, to change 5 inches to feet:

5/12 = 0.42 feet

**Example 3.2**

*Problem*

Change the following to feet: 2 inches, 3 inches, 4 inches, 8 inches.

*Solution*

2/12 = 0.167 feet
3/12 = 0.25 feet
4/12 = 0.33 feet
8/12 = 0.667 feet

## DECIMALS

While we often use fractions when using measurements, dealing with decimals is often easier when we do calculations, especially when working with pocket calculators. A decimal is composed of two sets of numbers. The numbers to the left of the decimal are whole numbers, and the numbers to the right of the decimal are parts of the whole number (fraction of a number), as shown below:

249.069

Whole number ↗ ↖ Fraction of a number

↑

Decimal

In order to solve decimal problems, the following key points are important:

- As mentioned, we often use fractions when dealing with measurements, but it is often easier to deal with decimals when we do the calculations, especially when we are working with pocket calculators and computers.
- We convert a fraction to a decimal by dividing.
- The horizontal line or diagonal line of the fraction indicates that we divide the bottom number into the top number. For example, to convert 4/5 to a decimal, we divide 4 by 5. Using a pocket calculator, enter the following keystrokes:

$$\boxed{4}\ \boxed{\div}\ \boxed{5}\ \boxed{=}$$

  The display will show the answer: 0.8.
- Relative values of place:
  0.1 — tenths
  0.01 — hundredths
  0.001 — thousandths
  0.0001 — ten thousandths
  0.00001 — hundred thousandths

When we use a calculator, we can convert a fraction to a decimal by dividing. The horizontal line or diagonal line of the fraction indicates that we divide the bottom number into the top number. For example, to convert 4/5 to a decimal, divide 4 by 5. Using a pocket calculator, enter the following keystrokes:

$$4 \div 5 =$$

- Reading numbers: 23,676 is read as "twenty-three thousand six hundred seventy-six."

✔ **Important Point:** "And" is not used in reading a whole number but instead is used to signify the presence of a decimal. For example, 23.676 is read "twenty-three and six hundred seventy-six thousandths," and 73.2658 is read "seventy-three and two thousand six hundred fifty-eight ten-thousandths."

### Example 3.3

*Problems*

Reduce the following fractions to decimals:

25/27 = ____________________
2/3 = ____________________
19/64 = ____________________
267/425 = ____________________
$21^{32}/_{625}$ = ____________________
$62^{1320}/_{2000}$ = ____________________

*Solutions*

0.9259
0.6667
0.2969
0.6282
21.0512
62.66

- When *subtracting* decimals, simply line up the numbers at the decimal and subtract. For example,

$$\begin{array}{r} 24.66 \\ \underline{-13.64} \\ 11.02 \end{array}$$

- To *add* decimal numbers, use the same rule as subtraction, line up the numbers on the decimal and add. For example,

$$\begin{array}{r} 24.66 \\ \underline{+13.64} \\ 38.30 \end{array}$$

- To *multiply* two or more decimal numbers follow these basic steps:
  - Multiply the numbers as whole numbers; do not worry about the decimals.
  - Write down the answer.
  - Count the total number of digits (numbers) to the right of the decimal in all of the numbers being multiplied; for example, $3.66 \times 8.8 = 32208$. Three digits are to the right of the decimal point (2 for the number 3.66 plus 1 for the number 8.8); therefore, the decimal point would be placed three places to the left from the right of the decimal place, which results in 32.208.
- To *divide* a number by a number containing a decimal, the divisor must be made into a whole number by moving the decimal point to the right until a whole number is obtained:
  - Count the number of places the decimal must be moved.
  - Move the decimal in the dividend by the same number of places.

✔ **Important Point:** Using a calculator simplifies working with decimals.

## PERCENT

The words *per cent* mean "by the hundred". Percentage is usually designated by the symbol %; thus, 15% means 15 percent or 15/100 or 0.15. These equivalents may be written in the reverse order: 0.15 = 15/100 = 15%. In water/wastewater treatment, percent is frequently used to express plant performance and control of biosolids treatment processes. When working with percent, the following key points are important:

- Percents are another way of expressing a part of a whole.
- As mentioned, the term *percent* means "by the hundred", so a percentage is the number out of 100. To determine percent, divide the quantity we wish to express as a percent by the total quantity then multiply by 100:

$$\text{Percent}(\%) = \frac{\text{Part}}{\text{Whole}} \tag{3.1}$$

- For example, 22 percent (or 22%) means 22 out of 100, or 22/100. Dividing 22 by 100 results in the decimal 0.22:

$$22\% = \frac{22}{100} = 0.22$$

- When operators use percentages in calculations (such as when used to calculate hypochlorite dosages and when the percent available chlorine must be considered), the percentage must be converted to an equivalent decimal number. This is accomplished by dividing the percentage by 100. For example, calcium hypochlorite (HTH) contains 65% available chlorine. What is the decimal equivalent of 65%? Because 65% means 65 per hundred, divide 65 by 100 (65/100), which is equal to 0.65.
- Decimals and fractions can be converted to percentages. The fraction is first converted to a decimal, then the decimal is multiplied by 100 to get the percentage. For example, if a 50-foot-high water tank has 26 feet of water in it, how full is the tank in terms of the percentage of its capacity?

$$\frac{25\text{ ft}}{50\text{ ft}} = 0.52\,(\text{decimal equivalent})$$

$$0.52 \times 100 = 52,\ \text{so the tank is 52\% full}$$

### Example 3.4

*Problem*

The plant operator removes 6500 gallons (gal) of biosolids from the settling tank. The biosolids contain 325 gal of solids. What is the percent solids in the biosolids?

*Solution*

$$\text{Percent} = \frac{325\text{ gal}}{6500\text{ gal}} \times 100$$

$$= 5\%$$

### Example 3.5

*Problem*

Convert 65% to decimal percent.

*Solution*

$$\text{Decimal percent} = \frac{\text{Percent}}{100}$$

$$= \frac{65}{100}$$

$$= 0.65$$

### Example 3.6

*Problem*

A sample of biosolids contains 5.8% solids. What is the concentration of solids (in decimal percent)?

*Solution*

$$\text{Decimal point} = \frac{5.8\%}{100} = 0.058$$

> ✓ **Key Point:** Unless otherwise noted, all calculations in the text using percent values require the percent to be converted to a decimal before use.

> ✓ **Key Point:** To determine what quantity a percent equals, first convert the percent to a decimal then multiply by the total quantity.

$$\text{Quantity} = \text{Total} \times \text{Decimal Percent} \tag{3.2}$$

### Example 3.7

*Problem*

Biosolids drawn from the settling tank contain 5% solids. If 2800 gallons of biosolids are withdrawn, how many gallons of solids are removed?

*Solution*

$$\text{Gallons} = \frac{5\%}{100} \times 2800 \text{ gal} = 140 \text{ gal}$$

### Example 3.8

*Problem*

Convert 0.55 to percent.

*Solution*

$$0.55 = \frac{55}{100} = 0.55 = 55\%$$

To convert 0.55 to 55%, we simply move the decimal point two places to the right.

### Example 3.9

*Problem*

Convert 7/22 to a decimal percent to a percent.

*Solution*

$$\begin{aligned}\frac{7}{22} &= 0.318\\ &= (0.318)(100)\\ &= 31.8\%\end{aligned}$$

# 4 Rounding and Significant Digits

**TOPICS**



## ROUNDING NUMBERS

When rounding numbers, the following key points are important:

- Numbers are rounded to reduce the number of digits to the right of the decimal point. This is done for convenience, not for accuracy.
- **Rule:** A number is rounded off by dropping one or more numbers from the right and adding zeroes if necessary to maintain the decimal point (see example). If the last figure dropped is 5 or more, increase the last retained figure by 1. If the last digit dropped is less than 5, do not increase the last retained figure.

### Example 4.1

*Problem*

Round off 10,546 to 4, 3, 2, and 1 significant figures.

*Solution*

10,546 = 10,550 to 4 significant figures
10,546 = 10,500 to 3 significant figures
10,546 = 11,000 to 2 significant figures
10,546 = 10,000 to 1 significant figure

## DETERMINING SIGNIFICANT FIGURES

To determine significant figures, the following key points are important:

- The concept of significant figures is related to rounding.
- It can be used to determine where to round off.

**Key Point:** No answer can be more accurate than the least accurate piece of data used to calculate the answer.

- **Rule:** Significant figures are those numbers that are known to be reliable. The position of the decimal point does not determine the number of significant figures.

### Example 4.2

*Problem*

How many significant figures are in a measurement of 1.35 in.?

*Solution*

Three significant figures: 1, 3, and 5.

### Example 4.3

*Problem*

How many significant figures are in a measurement of 0.000135?

*Solution*

Again, three significant figures: 1, 3, and 5. The three zeros are used only to place the decimal point.

### Example 4.4

*Problem*

How many significant figures are in a measurement of 103,500?

*Solution*

Four significant figures: 1, 0, 3, and 5. The remaining two zeros are used to place the decimal point.

### Example 4.5

*Problem*

How many significant figures are in 27,000.0?

*Solution*

There are six significant figures: 2, 7, 0, 0, 0, 0. In this case, the .0 means that the measurement is precise to 1/10 unit. The zeros indicate measured values and are not used solely to place the decimal point.

# 5 Powers of Ten and Exponents

## TOPICS



## RULES

In working with powers and exponents, the following key points are important:

- *Powers* are used to identify *area* (as in square feet) and volume (as in *cubic feet*).
- Powers can also be used to indicate that a number should be squared, cubed, etc. This later designation is the number of times a number must be multiplied times itself. For example, when several numbers are multiplied together, as $4 \times 5 \times 6 = 120$, the numbers, 4, 5, and 6 are the *factors*; 120 is the *product*.
- If all the factors are alike, such as $4 \times 4 \times 4 \times 4 = 256$, the product is called a *power*. Thus, 256 is a power of 4, and 4 is the *base* of the power. A power is a product obtained by using a base a certain number of times as a factor.
- Instead of writing $4 \times 4 \times 4 \times 4$, it is more convenient to use an *exponent* to indicate that the factor 4 is used as a factor four times. This exponent, a small number placed above and to the right of the base number, indicates how many times the base is to be used as a factor. Using this system of notation, the multiplication $4 \times 4 \times 4 \times 4$ can be written as $4^4$. The superscript 4 is the *exponent*, showing that 4 is to be used as a factor 4 times. These same considerations apply to letters (*a*, *b*, *x*, *y*, etc.) as well. For example:

$$z^2 = z \times z$$

$$z^4 = z \times z \times z \times z$$

✔ **Key Point:** When a number or letter does not have an exponent, it is considered to have an exponent of one.

| Powers of 1 | Powers of 10 |
|---|---|
| $1^0 = 1$ | $10^0 = 1$ |
| $1^1 = 1$ | $10^1 = 10$ |
| $1^2 = 1$ | $10^2 = 100$ |
| $1^3 = 1$ | $10^3 = 1000$ |
| $1^4 = 1$ | $10^4 = 10,000$ |

## EXAMPLES

### Example 5.1

*Problem*

How is the term $2^3$ written in expanded form?

*Solution*

The power (exponent) of 3 means that the base number (2) is multiplied by itself three times.

$$2^3 = 2 \times 2 \times 2$$

### Example 5.2

*Problem*

How is the term $(3/8)^2$ written in expanded form?

> ✓ **Key Point:** When parentheses are used, the exponent refers to the entire term within the parentheses.

*Solution*

$$(3/8)^2 = 3/8 \times 3/8$$

> ✓ **Key Point:** When a negative exponent is used with a number or term, a number can be expressed another way by using a positive exponent:

$$6^{-3} = 1/6^3$$

Another example is:

$$11^{-5} = 1/11^5$$

### Example 5.3

*Problem*

How is the term $8^{-3}$ written in expanded form?

$$8^{-3} = \frac{1}{8^3} = \frac{1}{8 \times 8 \times 8}$$

> ✓ **Key Point:** Any number or letter such as $3^0$ or $X^0$ does not equal $3 \times 1$ or $X \times 1$, but simply 1.

# 6 Averages (Arithmetic Mean) and Median

## TOPICS

- Averages
- Median

Whether we speak of harmonic mean, geometric mean, or arithmetic mean, each figure is designed to find the center (or middle) of a set of numbers. These terms capture the intuitive notion of a *central tendency* that may be present in the data. In statistical analysis, an *average of data* is a number that indicates the middle of the distribution of data values. The three most important measures of the center used in statistics are the *mean*, *median*, and the *mode*. In this chapter, we discuss mean and median.

## AVERAGES

An *average* represents several different measurements as a single number. Although averages can be useful by telling approximately how much or how many, they can also be misleading, as we demonstrate below. You will encounter two kinds of averages in waterworks/wastewater treatment calculations: the *arithmetic mean* (or simply *mean*) and the *median.*

> **Definition:** The *mean* (what we usually refer to as an *average*) is the total of a set of observations divided by the number of observations. We simply add up all of the individual measurements and divide by the total number of measurements taken.

### Example 6.1

*Problem*

The operator of a waterworks or wastewater treatment plant takes a chlorine residual measurement every day and part of the operating log is shown in Table 6.1. Find the mean.

*Solution*

Add up the seven chlorine residual readings: 0.9 + 1.0 + 0.9 + 1.3 + 1.1 + 1.4 + 1.2 = 7.8. Next, divide by the number of measurements (in this case, seven): 7.8 ÷ 7 = 1.11. The mean chlorine residual for the week was 1.11 mg/L.

## MEDIAN

The *median* is simply defined as the value of the central item when the data are arrayed by size. First, arrange all of the readings in either ascending or descending order, then find the middle value.

### Example 6.2

*Problem*

In our chlorine residual example, what is the median?

**TABLE 6.1**
**Daily Chlorine Residual Results**

| Day | Chlorine Residual (mg/L) |
|---|---|
| Monday | 0.9 |
| Tuesday | 1.0 |
| Wednesday | 0.9 |
| Thursday | 1.3 |
| Friday | 1.1 |
| Saturday | 1.4 |
| Sunday | 1.2 |

*Solution*

Arrange the values in ascending order:

0.9 0.9 1.0 1.1 1.2 1.3 1.4

The middle number is the fourth one (1.1), so, the median chlorine residual is 1.1 mg/L.

> **Key Point:** Usually the median will be a different value than the mean. If the number of values is an even number, one more step must be added, as there is no middle value. Find the two values in the middle, and then find the mean of those two values.

### Example 6.3

*Problem*

A water system has four wells with the following capacities: 115 gpm, 100 gpm, 125 gpm, and 90 gpm. What are the mean and median pumping capacities?

*Solution*

The mean is:

$$\frac{115\text{ gpm} + 100\text{ gpm} + 125\text{ gpm} + 90\text{ gpm}}{4} = \frac{430}{4} = 107.5\text{ gpm}$$

To find the median, arrange the values in order:

90 gpm 100 gpm 115 gpm 125 gpm

With four values, we have no single middle value, so we must take the mean of the middle values:

$$\frac{100\text{ gpm} + 115\text{ gpm}}{2} = 107.5\text{ gpm}$$

At times, determining what the original numbers were like (e.g., range) is difficult (if not impossible) when dealing only with averages.

### Example 6.4

*Problem*

A water system has four storage tanks. Three of them have a capacity of 100,000 gallons (gal) each, while the fourth has a capacity of 1 million gallons. What is the mean capacity of the storage tanks?

*Solution*

The mean capacity of the storage tanks is:

$$\frac{100,000 + 100,000 + 100,000 + 1,000,000}{4} = 325,000 \text{ gal}$$

**Note:** Notice that no tank in Example 6.4 has a capacity anywhere close to the mean. The median capacity requires us to take the mean of the two middle values; because they are both 100,000 gal, the median is 100,000 gal. Although three of the tanks have the same capacity as the median, these data offer no indication that one of these tanks holds a million gallons, information that could be important for the operator to know.

### Example 6.5

*Problem*

Effluent biological oxygen demand (BOD) test results for the treatment plant during the month of August are shown in the table below. What is the average effluent BOD for the month of August?

| | |
|---|---|
| Test 1 | 22 mg/L |
| Test 2 | 33 mg/L |
| Test 3 | 21 mg/L |
| Test 4 | 13 mg/L |

*Solution*

$$\text{Average} = \frac{22 \text{ mg/L} + 33 \text{ mg/L} + 21 \text{ mg/L} + 13 \text{ mg/L}}{4} = 22.3 \text{ mg/L}$$

### Example 6.6

*Problem*

The following composite sampled solids (SS) concentrations were recorded for primary influent flow for a week. What is the average SS?

| | |
|---|---|
| Monday | 310 mg/L SS |
| Tuesday | 322 mg/L SS |
| Wednesday | 305 mg/L SS |
| Thursday | 326 mg/L SS |
| Friday | 313 mg/L SS |
| Saturday | 310 mg/L SS |
| Sunday | 320 mg/L SS |
| Total | 2206 mg/L SS |

*Solution*

$$\text{Average SS} = \frac{\text{Sum of All Measurements}}{\text{Number of Measurements Used}}$$

$$= \frac{2206 \text{ mg/L SS}}{7}$$

$$= 315.1 \text{ mg/L SS}$$

# 7 Solving for the Unknown

## TOPICS

- Equations
- Axioms
- Solving Equations
- Setting Up Equations

Many water/wastewater calculations involve the use of formulae and equations; for example, calculations used in process control operations may require the use of equations to solve for the unknown quantity. To make these calculations, we must first know the values for all but one of the terms of the equation to be used, but what is an equation? Put simply, an equation is a mathematical statement telling us that what is on one side of an equal sign (=) is equal to what is on the other side. For example, 4 + 5 = 9. Now suppose we decide to *add* 4 to the left side: 4 + 4 + 5. What must we do then? We must also add 4 to the right side: 4 + 9. Consider another equation: 6 + 2 = 8. If we *subtract* 3 from the left side (6 + 2 – 3), what must we do next? We must also subtract 3 from the right side: 8 – 3. It follows that if the right side is *multiplied* by a certain number, we must also multiply the left side by that same number. Finally, if one side is *divided* by, for example, 4, then we must also divide the other side by 4.

*The bottom line:* What we do to one side of the equation, we must do to the other side. This is the case, of course, because the two sides, by definition, are always equal.

## EQUATIONS

An *equation* states that two expressions or quantities are equal in value. The statement of equality $6x + 4 = 19$ is an equation that is algebraic shorthand for "the sum of 6 times a number plus 4 is equal to 19." It can be seen that the equation $6x + 4 = 19$ is much easier to work with than the equivalent sentence.

When thinking about equations, it is helpful to consider an equation as being similar to a balance. The equal sign tells us that two quantities are in balance (i.e., they are equal). Referring back to the equation $6x + 4 = 19$, the solution to this problem may be summarized in three steps:

Step (1) $6x + 4 = 19$
Step (2) $6x = 15$
Step (3) $x = 2.5$

✓ **Note:** Step 1 expresses the entire equation. Step 2 shows that 4 has been subtracted from both sides of the equation. In step 3, both sides have been divided by 6.

✓ **Key Point:** An equation is kept in balance (both sides of the equal sign are kept equal) by subtracting the same number from both sides (members), adding the same number to both, or dividing or multiplying both by the same number.

The expression $6x + 4 = 19$ is called a *conditional equation*, because it is true only when $x$ has a certain value. The number to be found in a conditional equation is called the *unknown number*, the *unknown quantity*, or, more briefly, the *unknown.*

✔ **Key Point:** Solving an equation is finding the value or values of the unknown that make the equation true.

Another equation is:

$$W = F \times D \tag{7.1}$$

where

$W$ = work
$F$ = force
$D$ = distance

$$\text{Work} = \text{Force (lb)} \times \text{distance (ft or in.)}$$

The resulting quantity is expressed in ft-lb or in.-lb.

In the equation $60 = (x)(2)$, how can we determine the value of $x$? By following the axioms presented next, the solution to the unknown is quite simple.

✔ **Key Point:** It is important to point out that the following discussion includes only what the axioms are and how they work.

## AXIOMS

- If equal numbers are added to equal numbers, the sums are equal
- If equal numbers are subtracted from equal numbers, the remainders are equal
- If equal numbers are multiplied by equal numbers, the products are equal
- If equal numbers are divided by equal numbers (except zero), the quotients are equal
- Numbers that are equal to the same number or to equal numbers are equal to each other
- Like powers of equal numbers are equal
- Like roots of equal numbers are equal
- The whole of anything equals the sum of all its parts

✔ **Note:** The second and fourth axioms were used to solve the equation $6x + 4 = 19$.

## SOLVING EQUATIONS

✔ **Key Point:** As mentioned, solving an equation requires determining the value or values of the unknown number or numbers in the equation.

### Example 7.1

*Problem*

Find the value of $x$ if $x - 8 = 2$.

*Solution*

Here it can be seen by inspection that $x = 10$, but inspection does not help in solving more complicated equations. However, if we notice that to determine that $x = 10$, 8 is added to each

member of the given equation, we have acquired a method or procedure that can be applied to similar but more complex problems. Given the equation:

$$x - 8 = 2$$

Add 8 to each member (the first axiom):

$$x = 2 + 8$$

Collecting the terms (that is, adding the second and eighth):

$$x = 10$$

**Example 7.2**

*Problem*

Solve for $x$, if $4x - 4 = 8$ (each side is in simplest terms).

*Solution*

$$4x = 8 + 4$$

The term –4 is moved to the right of the equal sign to become +4:

$$\begin{aligned} 4x &= 12 \\ \frac{4x}{4} &= \frac{12}{4} \text{ (divide both sides)} \\ x &= 3 \end{aligned}$$

The $x$ is alone on the left side and is equal to the value on the right.

**Example 7.3**

*Problem*

Solve for $x$, if $x + 10 = 15$.

*Solution*

Subtract 10 from each member (the second axiom):

$$x = 15 - 10$$

Collect the terms:

$$x = 5$$

**Example 7.4**

*Problem*

Solve for $x$ if $5x + 5 - 7 = 3x + 6$.

*Solution*

Collect the terms +5 and –7:

$$5x - 2 = 3x + 6$$

Add 2 to both members (the second axiom):

$$5x = 3x + 8$$

Subtract $3x$ from both members (the second axiom):

$$2x = 8$$

Divide both members by 2 (the fourth axiom):

$$x = 4$$

### Checking the Answer

After obtaining a solution to an equation, always check it. This is an easy process. All we need to do is substitute the solution for the unknown quantity in the given equation. If the two members of the equation are then identical, the number substituted is the correct answer.

### Example 7.5

*Problem*

Solve and check $4x + 5 - 7 = 2x + 6$.

*Solution*

$$\begin{aligned} 4x + 5 - 7 &= 2x + 6 \\ 4x - 2 &= 2x + 6 \\ 4x &= 2x + 8 \\ 2x &= 8 \\ x &= 4 \end{aligned}$$

Substitute the answer $x = 4$ in the original equation:

$$\begin{aligned} 4x + 5 - 7 &= 2x + 6 \\ 4(4) + 5 - 7 &= 2(4) + 6 \\ 16 + 5 - 7 &= 8 + 6 \\ 14 &= 14 \end{aligned}$$

Because the statement $14 = 14$ is true, the answer $x = 4$ must be correct.

## SETTING UP EQUATIONS

The equations discussed to this point were expressed in *algebraic* language. It is important to learn how to set up an equation by translating a sentence into an equation (into algebraic language) and then solving this equation. To set up an equation properly, the following suggestions and examples should help:

- Always read the statement of the problem carefully.
- Select the unknown number and represent it by some letter. If more than one unknown quantity exists in the problem, try to represent those numbers in terms of the same letter — that is, in terms of one quantity.
- Develop the equation using the letter or letters selected and then solve.

### Example 7.6

*Problem*

One number is 8 more than another. This larger number is 2 less than 3 times the smaller number. What are the two numbers?

*Solution*

Let $n$ represent the smaller number. Then $n + 8$ must represent the larger number; that is:

$$n + 8 = 3n - 2$$

$$n = 5 \text{ (small number)}$$

$$n + 8 = 13 \text{ (large number)}$$

### Example 7.7

*Problem*

If 5 times the sum of a number and 6 is increased by 3, the result is two less than 10 times the number. Find the number.

*Solution*

Let $n$ represent the number:

$$5(n + 6) + 3 = 10n - 2$$

$$n = 7$$

### Example 7.8

*Problem*

For the equation $2x + 5 = 10$, solve for $x$.

*Solution*

$$2x + 5 = 10$$

$$2x = 5$$

$$x = 5/2$$

$$x = 2\tfrac{1}{2}$$

**Example 7.9**

*Problem*

If $.5x - 1 = -6$, find $x$.

*Solution*

$$.5x - 1 = -6$$

$$.5x = -5$$

$$x = -10$$

# 8 Ratio and Proportion

## TOPICS



## RATIO

A *ratio* is the established relationship between two numbers. For example, if someone says, “I’ll give you four to one for the Redskins over the Cowboys in the Super Bowl,” what does that person mean? Four to one, or 4:1, is a ratio. If someone gives you 4 to 1, it is his $4 to your $1. As another more pertinent example, if an average of 3 cu ft of screenings is removed from each million gallons of wastewater treated, then the ratio of screenings removed (cu ft) to treated wastewater (MG) is 3:1. Ratios are normally written using a colon (such as 2:1) or are written as a fraction (such as 2/1).

## PROPORTION

A *proportion* is a statement that two ratios are equal. For example, 1 is to 2 as 3 is to 6, so 1:2 = 3:6. In this case, 1 has the same relation to 2 that 3 has to 6. What exactly is that relation? The number 1 is half the size of 2, and 3 is half the size of 6. Alternately, 2 is twice the size of 1, and 6 is twice the size of 3.

## WORKING WITH RATIO AND PROPORTION

When working with ratio and/or proportion, the following key points are important to remember.

- One place where fractions are used in calculations is when ratios and proportions are involved, such as calculating solutions.
- A ratio is usually stated in the form A is to B as C is to D, and we can write it as two fractions that are equal to each other:

$$\frac{A}{B} = \frac{C}{D}$$

- Cross-multiplying solves ratio problems; that is, we multiply the left numerator ($A$) by the right denominator ($D$) and say that is equal to the left denominator ($B$) times the right numerator ($C$):

$$A \times D = B \times C$$

$$AD = BC$$

- If one of the four items is unknown, the ratio is solved by dividing the two known items that are multiplied together by the known item multiplied by the unknown. For example, if 2 pounds (lb) of alum are needed to treat 500 gallons (gal) of water, how many pounds of alum will we need to treat 10,000 gallons? We can state this as a ratio: 2 pounds of alum is to 500 gallons of water as *x* pounds of alum is to 10,000 gallons. This is set up in this manner:

$$\frac{1 \text{ lb alum}}{500 \text{ gal water}} = \frac{x \text{ lb alum}}{10{,}000 \text{ gal water}}$$

- Cross-multiplying gives us:

$$500 \times x = 1 \times 10{,}000$$

- Transposing:

$$x = \frac{1 \times 10{,}000}{500}$$

$$x = 20 \text{ lb alum}$$

As an example of calculating proportion, assume that 5 gallons of fuel costs $5.40. How much does 15 gallons cost?

$$\frac{5 \text{ gal}}{\$5.40} = \frac{15 \text{ gal}}{\$y}$$

$$5 \times y = 15 \times 5.40 = 81$$

$$y = \frac{81}{5} = \$16.20$$

**Example 8.1**

*Problem*

If a pump will fill a tank in 20 hours (h) at 4 gallons per minute (gpm), how long will it take a 10-gpm pump to fill the same tank?

*Solution*

First, analyze the problem. Here, the unknown is some number of hours, but should the answer be larger or smaller than 20 hours? If a 4-gpm pump can fill the tank in 20 hours, a larger pump (10-gpm) should be able to complete the filling in less than 20 hours. Therefore, the answer should be less than 20 hours. Now set up the proportion:

$$\frac{x \text{ h}}{20 \text{ h}} = \frac{4 \text{ gpm}}{10 \text{ gpm}}$$

$$x = \frac{4 \times 20}{10}$$

$$x = 8 \text{ h}$$

### Example 8.2

*Problem*

Solve for $x$ in the proportion problem given below.

$$\frac{36}{180} = \frac{x}{4450}$$

*Solution*

$$\frac{4450 \times 36}{180} = x$$

$$x = 890$$

### Example 8.3

*Problem*

Solve for the unknown value $x$ in the problem given below.

$$\frac{3.4}{2} = \frac{6}{x}$$

*Solution*

$$3.4 \times x = 2 \times 6$$

$$x = \frac{2 \times 6}{3.4}$$

$$x = 3.53$$

### Example 8.4

*Problem*

One pound of chlorine is dissolved in 65 gallons of water. To maintain the same concentration, how many pounds of chlorine would have to be dissolved in 150 gallons of water?

*Solution*

$$\frac{1 \text{ lb}}{65 \text{ gal}} = \frac{x \text{ lb}}{150 \text{ gal}}$$

$$65 \times x = 1 \times 150$$

$$x = \frac{1 \times 150}{65}$$

$$x = 2.3 \text{ lb}$$

**Example 8.5**

*Problem*

It takes 5 workers 50 hours to complete a job. At the same rate, how many hours would it take 8 workers to complete the job?

*Solution*

$$\frac{5 \text{ workers}}{8 \text{ workers}} = \frac{x \text{ hours}}{50 \text{ hours}}$$

$$x = \frac{5 \times 50}{8}$$

$$x = 31.3 \text{ hours}$$

# 9 Dimensional Analysis

## TOPIC

- Dimensional Analysis in Problem Solving

## DIMENSIONAL ANALYSIS IN PROBLEM SOLVING

*Dimensional analysis* is a problem-solving method that uses the fact that the number 1 can multiply any number or expression without changing its value. It is a useful technique used to check if a problem is set up correctly. In using dimensional analysis to check a math setup, we work with the dimensions (units of measure) only — not with numbers. In order to use the dimensional analysis method, we must know how to perform three basic operations. Unit factors may be made from any two terms that describe the same or equivalent amounts of what we are interested in. For example, we know that:

1 inch = 2.54 centimeters

### Basic Operation 1

To complete a division of units, always ensure that all units are written in the same format; it is best to express a horizontal fraction (such as gal/ft$^2$) as a vertical fraction:

Horizontal to vertical

$$\text{gal/cu ft to } \frac{\text{gal}}{\text{cu ft}}$$

$$\text{psi to } \frac{\text{lb}}{\text{sq in.}}$$

The same procedures are applied in the following examples.

$$\text{ft}^3\text{/min becomes } \frac{\text{ft}^3}{\text{min}}$$

$$\text{s/min becomes } \frac{\text{s}}{\text{sq in.}}$$

### Basic Operation 2

We must know how to divide by a fraction. For example,

$$\frac{\frac{\text{lb}}{\text{d}}}{\frac{\text{min}}{\text{d}}} \text{ becomes } \frac{\text{lb}}{\text{d}} \times \frac{\text{d}}{\text{min}}$$

In the above, notice that the terms in the denominator were inverted before the fractions were multiplied. This is a standard rule that must be followed when dividing fractions.

Another example is:

$$\frac{mm^2}{\frac{mm^2}{m^2}} \text{ becomes } mm^2 \times \frac{m^2}{mm^2}$$

## Basic Operation 3

We must know how to cancel or divide terms in the numerator and denominator of a fraction. After fractions have been rewritten in the vertical form and division by the fraction has been re-expressed as multiplication, as shown above, then the terms can be canceled (or divided) out.

> **Key Point:** For every term that is canceled in the numerator of a fraction, a similar term must be canceled in the denominator, and vice versa, as shown below:

$$\frac{Kg}{d} \times \frac{d}{min} = \frac{kg}{min}$$

$$mm^2 \times \frac{m^2}{mm^2} = m^2$$

$$\frac{gal}{min} \times \frac{ft^3}{gal} = \frac{ft^3}{min}$$

How are units that include exponents calculated? When written with an exponent (such as $ft^3$), a unit can be left as is or put in expanded form — (ft)(ft)(ft) — depending on other units in the calculation. The point is that it is important to ensure that square and cubic terms are expressed uniformly, as sq ft, cu ft, $ft^2$, or $ft^3$. For dimensional analysis, the last form is preferred. For example, suppose we wish to convert a volume of 1400 $ft^3$ to gallons. We will use a factor of 7.48 gal/$ft^3$ in the conversions. The question then becomes do we multiply or divide by 7.48? In the above instance, it is possible to use dimensional analysis to answer this question. In order to determine if the math setup is correct, only the dimensions are used. First, try dividing the dimensions:

$$\frac{ft^3}{gal/ft^3} = \frac{ft^3}{\frac{gal}{ft^3}}$$

Then, the numerator and denominator are multiplied to get:

$$= \frac{ft^6}{gal}$$

So, by dimensional analysis, we determine that if we divide the two dimensions ($ft^3$ and gal/$ft^3$), the units of the answer are $ft^6$/gal, not gal. It is clear that division is not the correct way to go in making this conversion. What would have happened if we had multiplied the dimensions instead of dividing?

$$ft^3 \times gal/ft^3 = ft^3 \times \frac{gal}{ft^3}$$

Then we multiply the numerator and denominator to obtain:

$$= \frac{ft^3 \times gal}{ft^3}$$

And we cancel common terms to obtain:

$$= \frac{ft^3 \times gal}{ft^3}$$

Obviously, by multiplying the two dimensions ($ft^3$ and gal/$ft^3$), the answer will be in gallons, which is what we want. Thus, because the math setup is correct, we would then multiply the numbers to obtain the number of gallons.

$$1400 \text{ ft}^3 \times 7.48 \text{ gal/ft}^3 = 10{,}472 \text{ gal}$$

Now we will try another problem with exponents. We wish to obtain an answer in square feet. If we are given two terms — 70 $ft^3$/s and 4.5 ft/s — is the following math setup correct?

$$70 \text{ ft}^3\text{/s} \times 4.5 \text{ ft/s}$$

First, only the dimensions are used to determine if the math setup is correct. By multiplying the two dimensions, we get:

$$ft^3/s \times ft/s = \frac{ft^3}{s} \times \frac{ft^3}{s}$$

Then we multiply the terms in the numerators and denominators of the fraction:

$$= \frac{ft^3 \times ft}{s \times s}$$

$$= \frac{ft^4}{s^2}$$

Obviously, the math setup is incorrect because the dimension we want is not square feet; therefore, if we multiply the numbers as shown above, the answer will be wrong. Division of the two dimensions gives us.

$$ft^3/s = \frac{\frac{ft^3}{s}}{\frac{ft}{s}}$$

Invert the denominator and multiply to get:

$$= \frac{ft^3}{s} \times \frac{s}{ft}$$

$$= \frac{ft \times ft \times ft \times s}{s \times ft}$$

$$= \frac{\text{ft} \times \text{ft} \times \text{ft} \times \text{s}}{\text{s} \times \text{ft}}$$

$$= \text{ft}^2$$

Because the dimensions of the answer are square feet, this math setup is correct; therefore, dividing the numbers (as was done with the units) will give us the correct answer:

$$\frac{70 \ \text{ft}^3/\text{s}}{4.5 \ \text{ft/s}} = 15.56 \ \text{ft}^2$$

**Example 9.1**

*Problem*

We are given two terms — 5 m/s and 7 $m^2$ — and the answer to be obtained is in cubic meters per second ($m^3$/s). Is multiplying the two terms the correct math setup?

*Solution*

$$\text{m/s} \times \text{m}^2 = \frac{\text{m}^2}{\text{s}} \times \text{m}^2$$

Multiply the numerators and denominator of the fraction:

$$= \frac{\text{m} \times \text{m}^2}{\text{s}}$$

$$= \frac{\text{m}^3}{\text{s}}$$

Because the dimensions of the answer are cubic meters per second ($m^3$/s), the math setup is correct; therefore, we should multiply the numbers to get the correct answer:

$$5 \ \text{m/s} \times 7 \ \text{m}^2 = 35 \ \text{m}^3/\text{s}$$

**Example 9.2**

*Problem*

The flow rate in a water line is 2.3 $ft^3$/s. What is the flow rate expressed as gallons per minute (gal/min)?

*Solution*

Set up the math problem and then use dimensional analysis to check the math setup:

$$(2.3 \ \text{ft}^3/\text{s} \times 7.48 \ \text{gal/ft}^3 \times 60 \ \text{s/min}$$

Dimensional analysis is used to check the math setup:

$$\text{ft}^3/\text{s} \times \text{gal/ft}^3 \times \text{s/min} = \frac{\text{ft}^3}{\text{s}} \times \frac{\text{gal}}{\text{ft}^3} \times \frac{\text{s}}{\text{min}}$$

$$= \frac{ft^3}{s} \, \frac{gal}{ft^3} \, \frac{s}{min}$$

$$= \frac{gal}{min}$$

The math setup is correct as shown above; therefore, this problem can be multiplied out to get the answer in correct units:

$$2.3 \text{ ft}^3/\text{s} \times 7.48 \text{ gal/ft}^3 \times 60 \text{ s/min} = 1032.24 \text{ gal/min}$$

# 10 Units of Measurement, Conversions, and Electrical Calculations

## TOPICS



Most of the calculations made in the water/wastewater industry have *units* connected or associated with them. While the number tells us how many, the units tell us what we have. When we measure something, we always have to specify what units we are measuring in. For instance, if someone talks about 20 calcium oxide (lime), we have not learned much about what that quantity of 20 is. On the other hand, if someone refers to 20 ounces, pounds, or bags of lime, we know exactly what is meant. Many other units of quantity can be used, such as barrels and drums. These examples are for units of *quantity*, but we can measure many other things, all of which require units.

## UNITS OF MEASUREMENT

A basic knowledge of units of measurement and how to use them and convert them is essential. Water/wastewater operators should be familiar with the U.S. Customary System (USCS), as well as the English System and the International System of Units (SI). Some of the important units are summarized in Table 10,1, which gives some basic SI and USCS units of measurement that will be encountered. In the study of water/wastewater treatment plant math operations (and in actual practice), it is quite common to encounter both extremely large quantities and extremely small

**TABLE 10.1**
**Commonly Used Units**

| Quantity | SI Units | USCS Units |
|---|---|---|
| Length | Meter (m) | Feet (ft) |
| Mass | Kilogram (kg) | Pound (lb) |
| Temperature | Celsius (C) | Fahrenheit (F) |
| Area | Square meter ($m^2$) | Square foot ($ft^2$) |
| Volume | Cubic meter ($m^3$) | Cubic foot ($ft^3$) |
| Energy | Kilojoule (kJ) | British thermal unit (Btu) |
| Power | Watt (W) | Btu/hr |
| Velocity | Meters/second (m/sec) | Miles/hour (mi/hr) |

**TABLE 10.2**
**Common Prefixes**

| Quantity | Prefix | Symbol |
|---|---|---|
| $10^{-12}$ | Pico- | p |
| $10^{-9}$ | Nano- | n |
| $10^{-6}$ | Micro- | µ |
| $10^{-6}$ | Milli- | m |
| $10^{-2}$ | Centi- | c |
| $10^{-1}$ | Deci- | d |
| 10 | Deca- | da |
| $10^{2}$ | Hecto- | h |
| $10^{6}$ | Kilo- | k |
| $10^{6}$ | Mega- | M |

ones. For example, the concentrations of some toxic substance may be measured in parts per million (ppm) or parts per billion (ppb). To describe quantities that may take on such large or small values, it is useful to have a system of prefixes to accompany the units. Some of the more important prefixes are presented in Table 10.2.

**Key Point:** A part per million may be roughly described as an amount contained in a full shot glass sitting on the bottom of a standard-sized swimming pool; that is, the full shot glass is 1 ppm relative to the rest of the water contained in the pool.

## CONVERSION FACTORS

Sometimes we have to convert between different units. Suppose that a 60-inch piece of wood is attached to a 6-foot piece of wood. How long are they combined? Obviously, we cannot find the answer to this question by adding 60 to 6 because the two figures are given in different units. Before we can add the two numbers, we have to convert one of them to the units of the other, then, when we have two numbers in the same units, we can add them. In order to perform this conversion, we need a *conversion factor*. In this case, we have to know how many inches make up a foot. Knowing that 12 inches is 1 foot, we can perform the calculation in two steps as follows:

$$60 \text{ inches} = 60/12 = 5 \text{ feet}$$

$$5 \text{ feet} + 6 \text{ feet} = 11 \text{ feet}$$

From this example, it can be seen that a conversion factor changes known quantities in one unit of measure to an equivalent quantity in another unit of measure.

To make the conversion from one unit to another, we must know two things:

- The exact number that relates the two units
- Whether to multiply or divide by that number

When making conversions, confusion over whether to multiply or divide is common; on the other hand, the number that relates the two units is usually known and thus is not a problem. Understanding the proper methodology — the mechanics — for various operations requires practice and common sense.

Along with using the proper mechanics (and practice and common sense) in making conversions, probably the easiest and fastest method of converting units is to use a conversion table. The simplest conversion requires that the measurement be multiplied or divided by a constant value. For instance, in wastewater treatment, if the depth of biosolids on a drying bed is 0.85 feet, we would multiply by 12 inches per foot to convert the measured depth to inches (10.2 inches). Likewise, if the depth of the solids blanket in the secondary clarifier is measured as 16 inches, dividing by 12 inches per foot converts the depth measurement to feet (1.33 feet). Table 10.3 lists many of the conversion factors used in water/wastewater treatment. Note that the table is designed with a unit of measure in the left and right columns and a constant (conversion factor) in the center column.

**Key Point:** To convert in the opposite direction (i.e., inches to feet), divide by the factor rather than multiply.

## Weight, Concentration, and Flow

Using Table 10.3 to convert from one unit expression to another and vice versa is good practice; however, in making conversions to solve process computations in water/wastewater treatment, we must be familiar with conversion calculations based upon a relationship between weight, flow or volume, and concentration. The basic relationship is:

$$\text{Weight} = \text{Concentration} \times \text{Flow or Volume} \times \text{Factor} \tag{10.1}$$

Table 10.4 summarizes weight, volume, and concentration calculations. With practice, many of these calculations become second nature to operators; the calculations are important relationships and are used often in water/wastewater treatment process control calculations, so on-the-job practice does occur.

The following conversion factors are used extensively in water/wastewater operations and are commonly required to solve problems on licensure examinations; the operator should keep them handy:

- 7.48 gallons per $ft^3$ ($gal/ft^3$)
- 3.785 liters per gallon (L/gal)
- 454 grams per pound (g/lb)
- 1000 mL per liter (mL/L)

**TABLE 10.3**
**Conversion Table**

| To Convert | Multiply by | To Get |
|---|---|---|
| Feet | 12 | Inches |
| Yards | 3 | Feet |
| Yards | 36 | Inches |
| Inches | 2.54 | Centimeters |
| Meters | 3.3 | Feet |
| Meters | 100 | Centimeters |
| Meters | 1000 | Millimeters |
| Square yards | 9 | Square feet |
| Square feet | 144 | Square inches |
| Acres | 43,560 | Square feet |
| Cubic yards | 27 | Cubic feet |
| Cubic feet | 1728 | Cubic inches |
| Cubic feet (water) | 7.48 | Gallons |
| Cubic feet (water) | 62.4 | Pounds |
| Acre-feet | 43,560 | Cubic feet |
| Gallons (water) | 8.34 | Pounds |
| Gallons (water) | 3.785 | Liters |
| Gallons (water) | 3785 | Milliliters |
| Gallons (water) | 3785 | Cubic centimeters |
| Gallons (water) | 3785 | Grams |
| Liters | 1000 | Milliliters |
| Days | 24 | Hours |
| Days | 1440 | Minutes |
| Days | 86,400 | Seconds |
| Million gallons/day | 1,000,000 | Gallons/day |
| Million gallons/day | 1.55 | Cubic feet/second |
| Million gallons/day | 3.069 | Acre-feet/day |
| Million gallons/day | 36.8 | Acre-inches/day |
| Million gallons/day | 3785 | Cubic meters/day |
| Gallons/minute | 1440 | Gallons/day |
| Gallons/minute | 63.08 | Liters/minute |
| Pounds | 454 | Grams |
| Grams | 1000 | Milligrams |
| Pressure (psi) | 2.31 | Head, feet (water) |
| Horsepower | 33,000 | Foot-pounds/minute |
| Horsepower | 0.746 | Kilowatts |
| **To Get** | **Divide by** | **To Convert** |

- 1000 mg per gram (mg/g)
- 1 $ft^3$/sec (cfs) = 0.6465 million gallons/day (MGD)

✓ **Key Point:** Density (also called specific weight) is mass per unit volume and may be measured in lb/cu ft, lb/gal, grams/mL, or grams/cu meter. If we take a fixed volume container, fill it with a fluid, and weigh it, we can determine the density of the fluid (after subtracting the weight of the container).

- 8.34 pounds per gallon water — density = 8.34 lb/gal
- One milliliter of water weighs 1 gram — density = 1 gram/mL

**TABLE 10.4**
**Weight, Volume, and Concentration Calculations**

| To Calculate | Formula |
|---|---|
| Pounds (lb) | Concentration (mg/L) × tank volume (MG) × 8.34 lb/mg/L/MG |
| Pounds/day (lb/d) | Concentration (mg/L) × flow (MGD) × 8.34 lb/mg/L/MG/ |
| Million gallons/day (MGD) | Quantity (lb/d) ÷ [concentration (mg/L) × 8.34 lb/mg/L/MG] |
| Milligrams/liter (mg/L) | Quantity (lb/d) ÷ [tank volume (MG) × 8.34 lb/mg/L/MG] |
| Kilograms/liter (kg/L) | Concentration (mg/L) × volume (MG) × 3.785 lb/mg/L/MG |
| Kilograms/day (kg/day) | Concentration (mg/L) × flow (MGD) × 3.785 lb/mg/L/MG |
| Pounds/dry ton (lb/d.t.) | Concentration (Mg/kg) × 0.002 (lb/d.t./mg/kg) |

- 62.4 pound per $ft^3$ water — density = 8.34 lb/gal
- 8.34 lb/gal = 8.34 mg/L (converts dosage in mg/L into lb/day/MGD); for example, 1 mg/L × 10 MGD × 8.3 = 83.4 lb/day
- 1 psi = 2.31 feet of water (head)
- 1 foot head = 0.433 psi
- ˚F = 9/5(˚C + 32)
- ˚C = 5/9(˚F – 32)
- Average water usage: 100 gallons/capita/day (gpcd)
- Persons per single family residence: 3.7

## CONVERSIONS

**Note:** Use Table 10.3 and Table 10.4 to make the conversions indicated in the following example problems. Other conversions are presented in appropriate sections of the text.

### Typical Water/Wastewater Conversion Examples

#### Example 10.1

Convert cubic feet to gallons.

$$\text{Gallons} = \text{Cubic feet } (\text{ft}^3) \times \text{gal/ft}^3$$

*Problem*

How many gallons of biosolids can be pumped to a digester that has 3600 cubic feet of volume available?

*Solution*

$$\text{Gallons} = 3600 \text{ ft}^3 \times 7.48 \text{ gal/ft}^3 = 26{,}928 \text{ gal}$$

#### Example 10.2

Convert gallons to cubic feet.

$$\text{Cubic feet } \left(\text{ft}^3\right) = \frac{\text{gal}}{7.48 \text{ gal/ft}^3}$$

*Problem*

How many cubic feet of biosolids are removed when 18,200 gallons are withdrawn?

*Solution*

$$\text{Cubic feet}\left(\text{ft}^3\right) = \frac{18,200\ \text{gal}}{7.48\ \text{gal/ft}^3} = 2433\ \text{ft}^3$$

**Example 10.3**

Convert gallons to pounds.

$$\text{Pounds (lb)} = \text{Gallons (gal)} \times 8.34\ \text{lb/gal}$$

*Problem*

If 1650 gallons of solids are removed from the primary settling tank, how many pounds of solids are removed?

*Solution*

$$\text{Pounds (lb)} = 1650\ \text{gal} \times 8.34\ \text{lb/gal} = 13,761\ \text{lb}$$

**Example 10.4**

Convert pounds to gallons.

$$\text{Gallons} = \frac{\text{lb}}{8.34\ \text{lb/gal}}$$

*Problem*

How many gallons of water are required to fill a tank that holds 7540 pounds of water?

*Solution*

$$\text{Gallons} = \frac{7540\ \text{lb}}{8.34\ \text{lb/gal}} = 904\ \text{gal}$$

**Example 10.5**

Convert milligrams/liter to pounds.

> **Key Point:** For plant operations, concentrations in milligrams per liter (mg/L) or parts per million (ppm) determined by laboratory testing must be converted to quantities of pounds, kilograms, pounds per day, or kilograms per day.

$$\text{Pounds} = \text{Concentration (mg/L)} \times \text{volume (MG)} \times 8.34\ \text{lb/mg/L/MG}$$

*Problem*

The solids concentration in an aeration tank is 2580 mg/L. The aeration tank volume is 0.95 MG. How many pounds of solids are in the tank?

*Solution*

$$\text{Pounds} = 2580\ \text{mg/L} \times 0.95\ \text{MG} \times 8.34\ \text{lb/mg/L/MG} = 20,441.3\ \text{lb}$$

### Example 10.6

Convert milligrams per liter to pounds per day.

$$\text{Pounds/day} = \text{Concentration (mg/L)} \times \text{flow (MGD)} \times 8.34 \text{ lb/mg/L/MG}$$

*Problem*

How many pounds of solids are discharged per day when the plant effluent flow rate is 4.75 MGD and the effluent solids concentration is 26 mg/L?

*Solution*

$$\text{Pounds/day} = 26 \text{ mg/L} \times 4.75 \text{ MGD} \times 8.34 \text{ lb/mg/L/MG} = 1030 \text{ lb/day}$$

### Example 10.7

Convert milligrams per liter to kilograms per day.

$$\text{kg/day} = \text{Concentration (mg/L)} \times \text{volume (MG)} \times 3.785 \text{ kg/mg/L/MG}$$

*Problem*

The effluent contains 26 mg/L of $BOD_5$. How many kilograms per day of $BOD_5$ are discharged when the effluent flow rate is 9.5 MGD?

*Solution*

$$\text{kg/day} = 26 \text{ mg/L} \times 9.5 \text{ MG} \times 3.785 \text{ kg/mg/L/MG} = 934 \text{ kg/day}$$

### Example 10.8

Convert pounds to milligrams per liter.

$$\text{Concentration } (\text{mg/L}) = \frac{\text{Quantity (lb)}}{\text{Volume (MG)} \times 8.34 \text{ lb/mg/L/MG}}$$

*Problem*

The aeration tank contains 89,990 pounds of solids. The volume of the aeration tank is 4.45 MG. What is the concentration of solids in the aeration tank (in mg/L)?

*Solution*

$$\text{Concentration } (\text{mg/L}) = \frac{89{,}990 \text{ lb}}{4.45 \text{ MG} \times 8.34 \text{ lb/mg/L/MG}} = 2425 \text{ mg/L}$$

### Example 10.9

Convert pounds per day to milligrams per liter.

$$\text{Concentration } (\text{mg/L}) = \frac{\text{Quantity } (\text{lb/day})}{\text{Volume (MGD)} \times 8.34 \text{ lb/mg/L/MG}}$$

*Problem*

The disinfection process uses 4820 pounds per day of chlorine to disinfect a flow of 25.2 MGD. What is the concentration of chlorine applied to the effluent?

*Solution*

$$\text{Concentration}\ (\text{mg/L}) = \frac{4820}{25.2\ \text{MGD} \times 8.34\ \ \text{lb/mg/L/MG}} = 22.9\ \ \text{mg/L}$$

**Example 10.10**

Convert pounds to flow in million gallons per day.

$$\text{Flow} = \frac{\text{Quantity}\ (\text{lb/day})}{\text{Concentration}\ (\text{mg/L}) \times 8.34\ \ \text{lb/mg/L/MG}}$$

*Problem*

9640 pounds of solids must be removed from the activated biosolids process per day. The waste activated biosolids concentration is 7699 mg/L. How many million gallons per day of waste activated biosolids must be removed?

*Solution*

$$\text{Flow} = \frac{9640\ \text{lb}}{7699\ \ \text{mg/L} \times 8.34\ \ \text{lb/mg/L/MG}} = 0.15\ \text{MGD}$$

**Example 10.11**

Convert million gallons per day (MGD) to gallons per minute (gpm).

$$\text{Flow} = \frac{\text{Flow (MGD)} \times 1{,}000{,}000\ \text{gal/MG}}{1440\ \ \text{min/day}}$$

*Problem*

The current flow rate is 5.55 MGD. What is the flow rate in gallons per minute?

*Solution*

$$\text{Flow} = \frac{5.55\ \text{MGD} \times 1{,}000{,}000\ \ \text{gal/MG}}{1440\ \ \text{min/day}} = 3854\ \text{gpm}$$

**Example 10.12**

Convert million gallons per day (MGD) to gallons per day (gpd).

$$\text{Flow} = \text{Flow (MGD)} \times 1{,}000{,}000\ \text{gal/MG}$$

*Problem*

The influent meter reads 28.8 MGD. What is the current flow rate in gallons per day?

*Solution*

$$\text{Flow} = 28.8 \text{ MGD} \times 1{,}000{,}000 \text{ gal/MG} = 28{,}800{,}000 \text{ gpd}$$

**Example 10.13**

Convert million gallons per day (MGD) to cubic feet per second (cfs).

$$\text{Flow (cfs)} = \text{Flow (MGD)} \times 1.55 \text{ cfs/MGD}$$

*Problem*

The flow rate entering the grit channel is 2.89 MGD. What is the flow rate in cubic feet per second?

*Solution*

$$\text{Flow} = 2.89 \text{ MGD} \times 1.55 \text{ cfs/MGD} = 4.48 \text{ cfs}$$

**Example 10.14**

Convert gallons per minute (gpm) to million gallons per day (MGD).

$$\text{Flow (MGD)} = \frac{\text{Flow (gpm)} \times 1440 \text{ min/day}}{1{,}000{,}000 \text{ gal/MG}}$$

*Problem*

The flow meter indicates that the current flow rate is 1469 gpm. What is the flow rate (in MGD)?

*Solution*

$$\text{Flow (MGD)} = \frac{1469 \text{ gpm} \times 1440 \text{ min/day}}{1{,}000{,}000 \text{ gal/MG}} = 2.12 \text{ MGD (rounded)}$$

**Example10.15**

Convert gallons per day (gpd) to million gallons per day (MGD).

$$\text{Flow (MGD)} = \frac{\text{Flow (gal/day)}}{1{,}000{,}000 \text{ gal/MG}}$$

*Problem*

The totalizing flow meter indicates that 33,444,950 gallons of wastewater have entered the plant in the past 24 hrs. What is the flow rate in MGD?

*Solution*

$$\text{Flow} = \frac{33{,}444{,}950 \text{ gal/day}}{1{,}000{,}000 \text{ gal/MG}} = 33.44 \text{ MGD}$$

**Example 10.16**

Convert flow in cubic feet per second (cfs) to million gallons per day (MGD).

$$\text{Flow (MGD)} = \frac{\text{Flow (cfs)}}{1.55 \text{ cfs/MG}}$$

*Problem*

The flow in a channel is determined to be 3.89 cubic feet per second (cfs). What is the flow rate in million gallons per day (MGD)?

*Solution*

$$\text{Flow (MGD)} = \frac{3.89 \text{ cfs}}{1.55 \text{ cfs/MG}} = 2.5 \text{ MGD}$$

**Example 10.17**

*Problem*

The water in a tank weighs 675 pounds. How many gallons does it hold?

*Solution*

Water weighs 8.34 lb/gal; therefore:

$$\frac{675 \text{ lb}}{8.34 \text{ lb/gal}} = 80.9 \text{ gallons}$$

**Example 10.18**

*Problem*

A liquid chemical weighs 62 lb/cu ft. How much does a 5-gallon container of it weigh?

*Solution*

Solve for specific gravity; to obtain lb/gal, multiply by 5.

$$\text{Specific gravity} = \frac{\text{wt. chemical}}{\text{wt. water}}$$

$$\frac{62 \text{ lb/cu ft}}{62.4 \text{ lb/cu ft}} = 0.99$$

$$\text{Specific gravity} = \frac{\text{wt. chemical}}{\text{wt. water}}$$

$$0.99 = \frac{\text{wt. chemical}}{8.34 \text{ lb/gal}}$$

$$8.26 \text{ lb/gal} = \text{wt. chemical}$$

$$8.26 \text{ lb/gal} \times 5 \text{ gal} = 41.3 \text{ lb}$$

**Example 10.19**

*Problem*

A wooden piling with a diameter of 16 inches and a length of 16 feet weighs 50 lb/cu ft. If it is inserted vertically into a body of water, what vertical force is required to hold it below the water surface?

*Solution*

If this piling had the same weight as water, it would rest just barely submerged. Find the difference between its weight and that of the same volume of water — that is, the weight required to keep it down.

$$\begin{array}{r} 62.4 \text{ lb/cu ft (water)} \\ -50.0 \text{ lb/cu ft (piling)} \\ \hline 12.4 \text{ lb/cu ft difference} \end{array}$$

$$\text{Volume of piling} = .785 \times 1.33^2 \times 16 \text{ ft} = 22.21 \text{ cu ft}$$

$$12.4 \text{ lb/cu ft} \times 22.21 \text{ cu ft} = 275.4 \text{ lb (required to hold piling below water surface)}$$

**Example 10.20**

*Problem*

A liquid chemical with a specific gravity (SG) of 1.22 is pumped at a rate of 40 gpm. How many pounds per day are being delivered by the pump?

*Solution*

Solve for pounds pumped per minute; change to lb/day.

$$8.34 \text{ lb/gal water} \times 1.22 \text{ SG liquid chemical} = 10.2 \text{ lb/gal liquid}$$

$$40 \text{ gal/min} \times 10.2 \text{ lb/gal} = 408 \text{ lb/min}$$

$$408 \text{ lb/min} \times 1440 \text{ min/d} = 587{,}520 \text{ lb/day}$$

**Example 10.21**

*Problem*

A cinder block weighs 70 pounds in air. When immersed in water, it weighs 40 pounds. What are the volume and specific gravity of the cinder block?

*Solution*

The cinder block displaces 30 pounds of water; solve for cubic feet of water displaced (equivalent to volume of cinder block).

$$\frac{30 \text{ lb water displaced}}{62.4 \text{ lb/cu ft}} = 0.48 \text{ cu ft water displaced}$$

Cinder block volume = .48 cu ft and weighs 70 lb.

$$\frac{70 \text{ lb}}{.48 \text{ ft}^3} = 145.8 \text{ lb/cu ft density of cinder block}$$

$$\text{Specific gravity} = \frac{\text{density of cinder block}}{\text{density of water}}$$

$$= \frac{145.8 \text{ lb/cu ft}}{62.4 \text{ lb/cu ft}}$$

$$= 2.34$$

### TEMPERATURE CONVERSIONS

Most water/wastewater operators are familiar with the formulae used for Fahrenheit and Celsius temperature conversions:

$$^\circ C = 5/9\ (^\circ F - 32)$$

$$^\circ F = 9/5\ (^\circ C) + 32$$

The difficulty arises when one tries to recall these formulae from memory. Probably the easiest way to recall these important formulae is to remember three basic steps for both Fahrenheit and Celsius conversions:

- Add 40˚
- Multiply by the appropriate fraction (5/9 or 9/5)
- Subtract 40˚

Obviously, the only variable in this method is the choice of 5/9 or 9/5 in the multiplication step. To make the proper choice, you must be familiar with the two scales. The freezing point of water is 32˚ on the Fahrenheit scale and 0˚ on the Celsius scale. The boiling point of water is 212˚ on the Fahrenheit scale and 100˚ on the Celsius scale. What does all this mean?

> ✔ **Key Point:** Note, for example, that at the same temperature, higher numbers are associated with the Fahrenheit scale and lower numbers with the Celsius scale. This important relationship helps you decide whether to multiply by 5/9 or 9/5. We will now look at a few conversion problems to see how the three-step process works.

**Example 10.22**

Suppose that we wish to convert 240˚F to Celsius. Using the three-step process, we proceed as follows:

- Step 1: add 40˚.

$$240^\circ + 40^\circ = 280^\circ$$

- Step 2: multiply 280˚ by either 5/9 or 9/5.

Because the conversion is to the Celsius scale, we will be moving to a number *smaller* than 280. Through reason and observation, obviously, if 280 were multiplied by 9/5, the result would be almost the same as multiplying by 2, which would double 280 rather than make it smaller. If we multiply by 5/9, the result will be about the same as multiplying by 1/2. Because in this problem we wish to move to a smaller number, we should multiply by 5/9:

$$(5/9)\ (280^\circ) = 156.0^\circ C$$

- Step 3: now subtract 40˚.

$$156.0^\circ C - 40.0^\circ C = 116.0^\circ C$$

Thus, 240˚F = 116.0˚C.

### Example 10.23

Convert 22˚C to Fahrenheit.

- Step 1: add 40˚.

$$22^\circ + 40^\circ = 62^\circ$$

  Because we are converting from Celsius to Fahrenheit, we are moving from a smaller to a larger number, and 9/5 should be used in the multiplications:

- Step 2: Multiply by either 5/9 or 9/5.

$$(9/5)\ (62^\circ) = 112^\circ$$

- Step 3: Subtract 40°.

$$112^\circ - 40^\circ = 72^\circ$$

Thus, 22˚C = 72˚F. Obviously, knowing how to make these temperature conversion calculations is useful. However, in practical day-to-day operations, you may wish to use a temperature conversion table.

## Population Equivalent (PE) or Unit Loading Factor

When a wastewater characterization study is required, pertinent data are often unavailable. When this is the case, *population equivalent* or *unit per capita loading* factors are used to estimate the total waste loadings to be treated. If we know the biological oxygen demand (BOD) contribution of a discharger, we can determine the loading placed upon the wastewater treatment system in terms of equivalent number of people. The BOD contribution of a person is normally assumed to be 0.17 lb BOD/day. To determine the population equivalent of a wastewater flow, divide the lb BOD/day content by the lb BOD/day contributed per person (e.g., 0.17 lb BOD/day).

$$\text{PE (people)} = \frac{\text{BOD concentration (lb/day)}}{0.17\ \text{lb BOD/day/person}} \tag{10.2}$$

### Example 10.24

*Problem*

A new industry wishes to connect to a city’s collection system. The industrial discharge will contain an average BOD concentration of 389 mg/L, and the average daily flow will be 72,000 gallons per day. What is the population equivalent of the industrial discharge?

*Solution*

First, convert flow rate to million gallons per day:

$$\text{Flow} = \frac{72{,}000\ \text{gpd}}{1{,}000{,}000\ \text{gal/MG}} = 0.072\ \text{MGD}$$

Next, calculate the population equivalent:

$$\text{PE (people)} = \frac{389\ \text{mg/L} \times 0.072\ \text{MGD} \times 8.34\ \text{lb/mg/L/MG}}{0.17\ \text{lb BOD/person/day}} = 1374\ \text{people/day}$$

### Example 10.25

*Problem*

An industry proposes to discharge 3455 lb of $BOD_5$ to the town sewer system. What is the population equivalent of the proposed discharge?

*Solution*

$$\text{PE (people)} = \frac{3455 \text{ lb/day}}{0.17 \text{ lb BOD/person/day}} = 20{,}324 \text{ people}$$

### Example 10.26

*Problem*

A 0.5-MGD wastewater flow has a BOD concentration of 1600 mg/L BOD. Using an average of 0.17 lb BOD/day/person, what is the population equivalent of this wastewater flow?

*Solution*

✔ ***Hint:*** Do not forget to convert mg/L BOD to lb/d BOD, then divide by 0.17 lb BOD/day/person.

$$\text{Population equivalent} = \frac{\text{BOD (lb/day)}}{\text{lb BOD/day/person}}$$

$$= \frac{(1600 \text{ mg/L})(0.5 \text{ MGD})(8.34 \text{ lb/gal})}{0.17 \text{ lb BOD/day/person}}$$

$$= 39{,}247 \text{ people}$$

## Specific Gravity and Density

Earlier, we presented a few specific gravity and density conversion example problems. *Specific gravity* is the ratio of the density of a substance to that of a standard material under standard conditions of temperature and pressure. The specific gravity of water is 1. Any substance with a density greater than that of water will have a specific gravity greater than 1.0, and any substance with a density less than that of water will have specific gravity less than 1.0. Specific gravity can be used to calculate the weight of a gallon of liquid chemical.

$$\text{Chemical (lb/gal)} = \text{water (lb/gal)} \times \text{specific gravity (chemical)} \tag{10.3}$$

### Example 10.27

*Problem*

The label states that a ferric chloride solution has a specific gravity of 1.58. What is the weight of 1 gallon of ferric chloride solution?

*Solution*

$$\text{Ferric chloride} = 8.34 \text{ lb/gal} \times 1.58 = 13.2 \text{ lb/gal}$$

### Example 10.28

*Problem*

If we say that the density of gasoline is 43 lb/cu ft, what is the specific gravity of gasoline?

*Solution*

The specific gravity of gasoline is the comparison (or ratio) of the density of gasoline to that of water:

$$\text{Specific gravity} = \frac{\text{density of gasoline}}{\text{density of water}} = \frac{43\ \text{lb/cu ft}\ (\text{density of gasoline})}{62.4\ \text{lb/cu ft}\ (\text{density of water})} = 0.69$$

> ✔ **Key Point:** Because the specific gravity of gasoline is less than 1 (lower than the specific gravity of water), it will float in water. If its specific gravity were greater than that of water, then it would sink.

## Flow

*Flow* is expressed in many different terms in the English system of measurement. The most commonly used flow terms are as follows:

- gpm — gallons per minute
- cfs — cubic feet per second
- gpd — gallons per day
- MGD — million gallons per day

In converting flow rates, the most common flow conversions are 1 cfs = 448 gpm and 1 gpm = 1440 gpd. To convert gallons per day to MGD, divide the gpd by 1,000,000. For example, convert 150,000 gallons to MGD:

$$\frac{150{,}000\ \text{gpd}}{1{,}000{,}000} = 0.150\ \text{MGD}$$

In some instances, flow is given in MGD but is needed in gpm. To make the conversion (MGD to gpm), two steps are required.

- Step 1: convert the gpd by multiplying by 1,000,000.
- Step 2: convert to gpm by dividing by the number of minutes in a day (1440 min/day).

### Example 10.29

*Problem*

Convert 0.135 MGD to gpm.

*Solution*

First convert the flow in MGD to gpd.

$$0.135\ \text{MGD} \times 1{,}000{,}000 = 135{,}000\ \text{gpd}$$

Now convert to gpm by dividing by the number of minutes in a day (24 hrs per day × 60 min per hour = 1440 min/day).

$$\frac{135{,}000\ \text{gpd}}{1440\ \text{min/day}} = 93.8 \text{ or } 94\ \text{gpm}$$

In determining flow through a pipeline, channel, or stream, we use the following equation:

$$Q = VA \tag{10.4}$$

where

$Q$ = cubic feet per second (cfs)
$V$ = velocity in feet per second (ft/sec)
$A$ = area in square feet (ft$^2$)

### Example 10.30

*Problem*

Find the flow in cubic feet per second (cfs) in an 8-inch line if the velocity is 3 feet per second.

*Solution*

- Step 1: Determine the cross-sectional area of the line in square feet. Start by converting the diameter of the pipe to inches
- Step 2: The diameter is 8 inches; therefore, the radius is 4 inches, and 4 inches is 4/12 of a foot, or 0.33 feet.
- Step 3: Find the area in square feet

$$A = \pi r^2$$

$$A = \pi(0.33\ \text{ft})^2$$

$$A = \pi \times 0.109\ \text{ft}^2$$

$$A = 0.342\ \text{ft}^2$$

- Step 4: $Q = VA$

$$Q = 3\ \text{ft/sec} \times 0.342\ \text{ft}^2$$

$$Q = 1.03\ \text{cfs}$$

### Example 10.31

*Problem*

Find the flow in gpm when the total flow for the day is 75,000 gpd.

*Solution*

$$\frac{75{,}000\ \text{gpd}}{1440\ \text{min/day}} = 52\ \text{gpm}$$

### Example 10.32

*Problem*

Find the flow in gpm when the flow is 0.45 cfs.

*Solution*

$$0.45\frac{\text{cfs}}{1} \times \frac{448\ \text{gpm}}{1\ \text{cfs}} = 202\ \text{gpm}$$

## Detention Time

*Detention time* is the length of time water is retained in a vessel or basin or the period from the time the water enters a settling basin until it flows out the other end. When calculating unit process detention times, we are calculating the length of time it takes the water to flow through that unit process. Detention times are normally calculated for the following basins or tanks:

- Flash mix chambers (seconds)
- Flocculation basins (minutes)
- Sedimentation tanks or clarifiers (hours)
- Wastewater ponds (days)
- Oxidation ditches (hours)

To calculate the detention period of a basin, the volume of the basin must first be obtained. Using a basin 70 ft long ($L$), 25 ft wide ($W$), and 12 ft deep ($D$), the volume ($V$) would be:

$$V = L \times W \times D$$

$$V = 70\text{ ft} \times 25\text{ ft} \times 12\text{ ft}$$

$$V = 21{,}000\text{ ft}^3$$

$$\text{Gallons} = V \times 7.48\text{ gal/ft}^2$$

$$\text{Gallons} = 21{,}000 \times 7.48 = 157{,}080\text{ gallons}$$

If we assume that the plant filters 300 gpm, then we have 157,080 ÷ 300 = 524 minutes, or roughly 9 hours, of detention time. Stated another way, the detention time is the length of time theoretically required for the coagulated water to flow through the basin.

✔ **Key Point:** If detention time is desired in minutes, then the flow rate used in the calculation should have the same time frame (cfm or gpm, depending on whether tank volume is expressed as cubic feet or gallons). If detention time is desired in hours, then the flow rate used in the calculation should be cfh or gph.

If chlorine is added to the water as it enters the basin, the chlorine contact time (CT) would be 9 hours. That is, to determine the CT (concentration of free chlorine residual × disinfectant contact time [in minutes] used to determine the effectiveness of chlorine), we must calculate detention time.

✔ **Key Point:** True detention time is the T portion of the CT value.

Detention time, of course, is calculated in units of time. The most common are seconds, minutes, hours, and days. Examples of detention time equations where time and volume units match include:

$$\text{Detention time (sec)} = \frac{\text{volume of tank (cu ft)}}{\text{flow rate (cfs)}} \tag{10.5}$$

$$\text{Detention time (min)} = \frac{\text{volume of tank (gal)}}{\text{flow rate (gpm)}} \tag{10.6}$$

$$\text{Detention time (hrs)} = \frac{\text{volume of tank (gal)}}{\text{flow rate (gph)}} \tag{10.7}$$

$$\text{Detention time (days)} = \frac{\text{volume of tank (gal)}}{\text{flow rate (gph)}} \tag{10.8}$$

The simplest way to calculate detention time is to divide the volume of the container by the flow rate into the container. The theoretical detention time of a container is the same as the amount of time it would take to fill the container if it were empty. For volume, the most common units used are gallons; however, on occasion, cubic feet may also be used. Time units will be in whatever units are used to express the flow. For example, if the flow is in gpm, the detention time will be in days. If, in the final result, the detention time is in the wrong time unit, simply convert to the appropriate units.

### Example 10.33

*Problem*

The reservoir for the community holds 110,000 gallons. The well will produce 60 gpm. What is the detention time in the reservoir in hours?

*Solution*

$$\text{DT} = \frac{110{,}000 \text{ gal}}{60 \text{ gal/min}} = 1834 \text{ min or } \frac{1834 \text{ min}}{60 \text{ min/hr}} = 30.6 \text{ hr}$$

### Example 10.34

*Problem*

Find the detention time in a 55,000-gallon reservoir if the flow rate is 75 gpm.

*Solution*

$$\text{DT} = \frac{55{,}000 \text{ gal}}{75 \text{ gal/min}} = 734 \text{ min or } \frac{734 \text{ min}}{60 \text{ min/hr}} = 1 \text{ hr}$$

### Example 10.35

*Problem*

If the fuel consumption to the boiler is 30 gallons per day, how many days will the 1000-gallon tank last?

*Solution*

$$\text{Days} = \frac{1000 \text{ gal}}{30 \text{ gal/days}} = 33.3 \text{ days}$$

## Chemical Addition Conversions

One of the most important water/wastewater operator functions is to make various chemical additions to unit processes. In this section, we demonstrate how to calculate the required amount of chemical (active ingredient), required amount of chemical, dry chemical feed rate, and liquid chemical feed rate.

### Required Amount of Chemical (Active Ingredient)

$$\text{Chemical (lb/day)} = \text{Required dose (mg/L)} \times \text{Flow (MGD)} \times 8.34\ \text{lb/mg/L/MG} \qquad (10.9)$$

### Example 10.36

*Problem*

The laboratory jar test indicates a required dose of 4.1 mg/L of ferric chloride. The flow rate is 5.15 MGD. How many pounds of ferric chloride will be needed each day?

*Solution*

$$\text{Required amount (lb/d)} = 4.1\ \text{mg/L} \times 5.15\ \text{MGD} \times 8.34\ \text{lb/mg/L/MG} = 176.1\ \text{lb/day}$$

### Required Amount of Chemical

Because industrial-strength chemicals are normally less than 100% active ingredient, the amount of chemical must be adjusted to compensate for the inactive components.

$$\text{Required amount}\left(\text{lb/day}\right) = \frac{\text{active ingredient required}\left(\text{lb/day}\right)}{\%\ \text{active ingredient}} \qquad (10.10)$$

### Example 10.37

*Problem*

To achieve the desired phosphorus removal, 180 pounds of ferric chloride must be added to the daily flow. The feed solution is 66% ferric chloride. How many pounds of feed solution will be needed?

*Solution*

$$\text{Required amount}\left(\text{lb/day}\right) = \frac{180\ \text{lb/day}}{0.66} = 273\ \text{lb/day}$$

### Dry Chemical Feed Rate

When chemical is to be added in dry (powder, granular, etc.) form, the chemical feed rate can be expressed in units such as pounds per hour or grams per minute.

$$\text{Feed rate}\left(\text{lb/hr}\right) = \frac{\text{required amount}\left(\text{lb/day}\right)}{24\ \text{hour/day}} \qquad (10.11)$$

$$\text{Feed rate}\left(\text{g/min}\right) = \frac{\text{required amount}\left(\text{lb/day}\right) \times 454\ \text{g/lb}}{1440\ \text{min/day}} \qquad (10.12)$$

### Example 10.38

*Problem*

The plant must feed 255 pounds per day of high-test hypochlorite (HTH) powder chlorine to reduce odors. What is the required feed rate in (1) pounds per hour, and (2) grams per minute?

*Solution*

$$\text{Feed rate}\ (\text{lb/hr}) = \frac{255\ \text{lb/day}}{24\ \text{hr/day}} = 10.6\ \text{lb/hr}$$

$$\text{Feed rate}\ (\text{g/min}) = \frac{255\ \text{lb/day} \times 454\ \text{g/lb}}{1440\ \text{min/day}} = 80\ \text{g/min}$$

### Liquid Chemical Feed Rate

If chemical is fed in liquid form, the required amount (pounds, grams, etc.) of process chemical must be converted to an equivalent volume (gallons, milliliters, etc.). This volume is then converted to the measurement system of the solution feeder (gallons/day, milliliters/minute, etc.).

> ✓ Key Point: The weight of a gallon of the process chemical is usually printed on the container label or the material safety data sheet (MSDS), or weight per gallon can be determined if the specific gravity of the chemical is supplied.

$$\text{Feed rate}\ (\text{gpd}) = \frac{\text{required amount of chemical}\ (\text{lb/day})}{\text{weight per gallon}\ (\text{lb/gal})} \tag{10.13}$$

$$\text{Feed rate}\ (\text{gpm}) = \frac{\text{required amount of chemical}\ (\text{lb/day})}{\text{weight per gallon}\ (\text{lb/gal}) \times 1440\ \text{min/day}} \tag{10.14}$$

$$\text{Feed rate}\ (\text{mL/min}) = \frac{\text{required amount}\ (\text{lb/day}) \times 3785\ \text{mL/gal}}{\text{wt/gal}\ (\text{lb/gal}) \times 1440\ \text{min/day}} \tag{10.15}$$

### Example 10.39

*Problem*

To achieve phosphorus removal, the plant must add 812 lb of ferric chloride feed solution each day. The ferric chloride solution weighs 11.1 lb/gallon. What is the required feed rate (a) in gallons per day; (b) gallons per minute; and (c) milliliters per minute?

*Solution*

$$\text{Feed rate}\ (\text{gpd}) = \frac{812\ \text{lb/day}}{11.1\ \text{lb/gal}} = 73\ \text{gpd} \tag{a}$$

$$\text{Feed rate}\ (\text{gpm}) = \frac{812\ \text{lb/day}}{11.1\ \text{lb/gal} \times 1440\ \text{min/day}} = 0.05\ \text{gpm} \tag{b}$$

$$\text{Feed rate}\ (\text{mL/min}) = \frac{812\ \text{lb/day} \times 3785\ \text{mL/gal}}{11.1\ \text{lb/gal} \times 1440\ \text{min/day}} = 192\ \text{mL/min} \tag{c}$$

## Horsepower and Energy Costs

In water/wastewater treatment and ancillaries, *horsepower* is a common expression for power. One horsepower is equal to 33,000 foot pounds (ft-lb) of work per minute. This value is determined,

for example, for selecting the pump or combination of pumps to ensure an adequate pumping capacity (a major use of calculating horsepower in water/wastewater treatment). Pumping capacity depends upon the flow rate desired and the feet of head against which the pump must pump (also referred to as *effective height*).

Calculations of horsepower are made in conjunction with many treatment plant operations. The basic concept from which the horsepower calculation is derived is the concept of *work*, which involves the operation of a force (lb) over a specific distance (ft). The *amount of work* accomplished is measured in foot-pounds:

$$\text{ft} \times \text{lb} = \text{ft-lb} \tag{10.16}$$

The *rate of doing work* (*power*) involves a time factor. Originally, the rate of doing work or power compared the power of a horse to that of a steam engine. The rate at which a horse could work was determined to be about 550 ft-lb/sec (or 33,000 ft-lb/min). This rate has become the definition of the standard unit called horsepower (see Equation 10.17).

### Horsepower (hp)

$$\text{Horsepower (hp)} = \frac{\text{power (ft-lb/min)}}{33{,}000\ \text{ft-lb/min/hp}} \tag{10.17}$$

As mentioned, in water/wastewater treatment the major use of horsepower calculation is in pumping stations. When used for this purpose, the horsepower calculation can be modified as shown below.

#### *Water Horsepower (whp)*

- The amount of power required to move a given volume of water a specified total head is known as water horsepower.

$$\text{whp} = \frac{\text{pump rate (gpm)} \times \text{total head (ft)} \times 8.34\ \text{lb/gal}}{33{,}000\ \text{ft-lb/min/hp}} \tag{10.18}$$

### Example 10.40

*Problem*

A pump must deliver 1210 gpm to a total head of 130 feet. What is the required water horsepower?

*Solution*

$$\text{whp} = \frac{1210\ \text{gpm} \times 130\ \text{ft} \times 8.34\ \text{lb/gal}}{33{,}000\ \text{ft-lb/min/hp}} = 40\ \text{whp}$$

#### *Brake Horsepower (bhp)*

- Brake horsepower (bhp) refers to the horsepower supplied to the pump from the motor. As power moves through the pump, additional horsepower is lost from slippage and friction of the shaft and other factors; thus, pump efficiencies range from about 50% to 85%, and pump efficiency must be taken into account.

$$\text{bhp} = \frac{\text{whp}}{\text{pump efficiency (\%)}} \tag{10.19}$$

**Example 10.41**

*Problem*

Under the specified conditions, the pump efficiency is 73%. If the required water horsepower is 40 hp, what is the required brake horsepower?

*Solution*

$$\text{bhp} = \frac{40 \text{ whp}}{0.73} = 55 \text{ bhp}$$

*Motor Horsepower (mhp)*

- Motor horsepower (mhp) is the horsepower the motor must generate to produce the desired brake and water horsepower.

$$\text{mhp} = \frac{\text{brake horsepower (bhp)}}{\text{motor efficiency (\%)}} \tag{10.20}$$

**Example 10.42**

*Problem*

The motor is 93% efficient. What is the required motor horsepower when the required brake horsepower is 49.0 bhp?

*Solution*

$$\text{mhp} = \frac{49 \text{ bhp}}{0.93} = 53 \text{ mhp}$$

## Electrical Power

On occasion, water/wastewater operators (especially senior operators) must make electrical power calculations — especially regarding electrical energy required/consumed during a period of time. To accomplish this, horsepower is converted to electrical energy (kilowatts), then multiplied by the hours of operation to obtain kilowatt-hours.

$$\text{Kilowatt-hours} = \text{hp} \times 0.746 \text{ kW/hp} \times \text{operating time (hr)}$$

**Example 10.43**

*Problem*

A 60-horsepower motor operates at full load 12 hours per day, 7 days a week. How many kilowatts of energy does it consume per day?

*Solution*

$$\text{Kilowatt-hours/day} = 60 \text{ hp} \times 0.746 \text{ kW/hp} \times 12 \text{ hr/day} = 537 \text{ kWh/day}$$

Given the cost per kilowatt-hour, the operator (or anyone else) may calculate the cost of power for any given period of operation.

$$\text{Cost} = \text{power required/day} \times \text{kW-hr/day} \times \text{days/period} \times \text{cost/kW-hr} \tag{10.21}$$

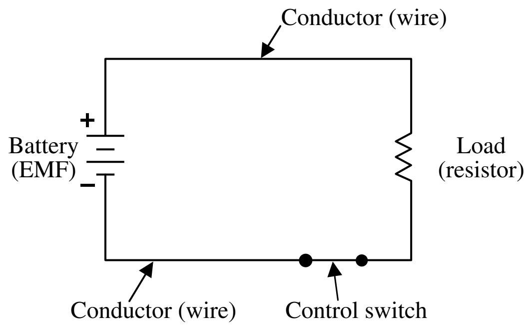


**FIGURE 10.1** Simple closed circuit.

*Problem*

A 60-horsepower motor requires 458 kW-hr/day. The pump is in operation every day. The current cost of electricity is $0.0328 per kilowatt-hour. What is the yearly electrical cost for this pump?

*Solution*

$$\text{Cost (\$)} = 458 \text{ kW-hr/day} \times 365 \text{ days/year} \times \$0.0328/\text{kW-hr} = \$5483.18$$

## ELECTRICAL CALCULATIONS

On many state licensure examinations, practical electrical problems are presented. The operator who takes these exams is required to perform very basic electrical computations. Moreover, whether required for licensure or not, many operators are required to perform electrical maintenance and installations that require basic computations. It should be pointed out, however, that only qualified electricians should perform electrical work of any type.

An electric circuit includes an *energy source*, which is a source of electromotive force (emf) or voltage (that is, a battery or generator); a *conductor* (wire); a *load*; and a means of *control* (see Figure 10.1). The energy source could be a battery, as in Figure 10.1, or some other means of producing a voltage. The load that dissipates the energy could be a lamp, a resistor, or some other device (or devices) that does useful work, such as an electric toaster, a power drill, radio, or a soldering iron. Conductors are wires that offer low resistance to current; they connect all the loads in the circuit to the voltage source. No electrical device dissipates energy unless current flows through it. Because conductors, or wires, are not perfect conductors, they heat up (dissipate energy) so they are actually part of the load. For simplicity, however, we usually think of the connecting wiring as having no resistance, as it would be tedious to assign a very low resistance value to the wires every time we wanted to solve a problem. Control devices might be switches, variable resistors, circuit breakers, fuses, or relays.

### OHM'S LAW

Simply put, *Ohm's law* defines the relationship between current, voltage, and resistance in electric circuits. Ohm's law can be expressed mathematically in three ways.

- The *current* ($I$) in a circuit is equal to the voltage applied to the circuit divided by the resistance of the circuit. Stated another way, the current in a circuit is *directly* proportional to the applied voltage and *inversely* proportional to the circuit resistance. Ohm's law may be expressed as an equation:

$$I = \frac{E}{R} \tag{10.22}$$

where

$I$ = current in amperes (A)
$E$ = voltage in volts (V)
$R$ = resistance in ohms (Ω)

- The *resistance* ($R$) of a circuit is equal to the voltage applied to the circuit divided by the current in the circuit:

$$R = \frac{E}{I} \tag{10.23}$$

- The applied *voltage* ($E$) to a circuit is equal to the product of the current and the resistance of the circuit:

$$E = I \times R = IR \tag{10.24}$$

If any two of the quantities in Equation 10.22 to Equation 10.24 are known, the third may be easily found. Let us look at an example.

### Example 10.44

*Problem*

Figure 10.2 shows a circuit containing a resistance of 6 ohms and a source of voltage of 3 volts. How much current flows in the circuit?

$$E = 3 \text{ volts}$$

$$R = 6 \text{ ohms}$$

$$I = ?$$

*Solution*

$$I = \frac{E}{R}$$

$$I = \frac{3}{6}$$

$$I = 0.5 \text{ amperes}$$

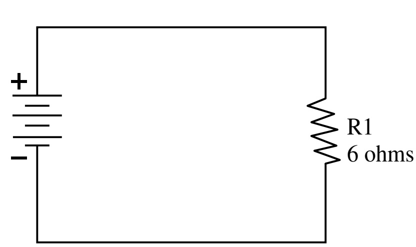


**FIGURE 10.2** Determining current in a simple current.

To observe the effect of source voltage on circuit current, we use the circuit shown in Figure 10.2 but double the voltage to 6 volts.

### Example 10.45

*Problem*

$$E = 6 \text{ volts}$$

$$R = 6 \text{ ohms}$$

$$I = ?$$

*Solution*

$$I = \frac{E}{R}$$

$$I = \frac{6}{6}$$

$$I = 1 \text{ ampere}$$

Notice that as the source of voltage doubles, the circuit current also doubles.

> **The Key Point:** Circuit current is directly proportional to applied voltage and will change by the same factor that the voltage changes.

To verify that current is inversely proportional to resistance, assume the resistor in Figure 10.2 has a value of 12 ohms.

### Example 10.46

*Problem*

$$E = 3 \text{ volts}$$

$$R = 12 \text{ ohms}$$

$$I = ?$$

*Solution*

$$I = \frac{E}{R}$$

$$I = \frac{3}{12}$$

$$I = 0.25 \text{ amperes}$$

Comparing this current of 0.25 ampere for the 12-ohm resistor to the 0.5 ampere of current obtained with the 6-ohm resistor shows that doubling the resistance will reduce the current to one half the original value. The point is that the circuit current is inversely proportional to the circuit resistance.

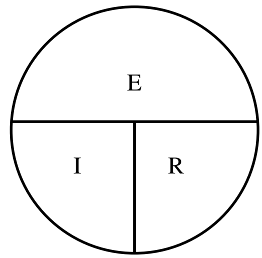


**FIGURE 10.3** Ohm's Law circle.

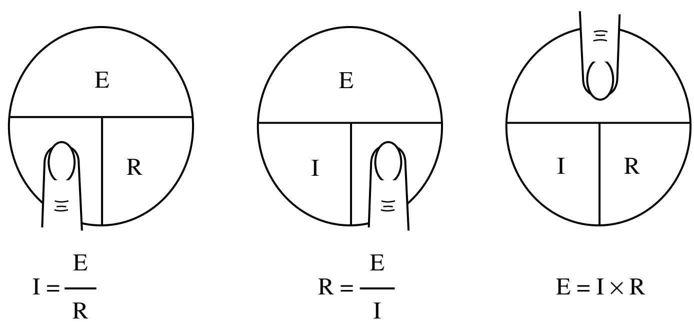


**FIGURE 10.4** Putting the Ohm's Law circle to work.

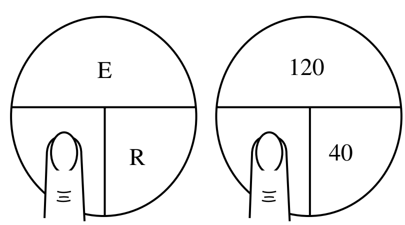


**FIGURE 10.5**

Recall that if you know any two of the three quantities *E*, *I*, and *R*, you can calculate the third. In many circuit applications, current is known and either the voltage or the resistance will be the unknown quantity. To solve a problem, in which current and resistance are known, the basic formula for Ohm's law must be transposed to solve for *E*, for *I*, or for *R*. However, Ohm's law equations can be memorized and practiced effectively by using an Ohm's law circle (see Figure 10.3). To find the equation for *E*, *I*, or *R* when two quantities are known, cover the unknown third quantity with your finger, a ruler, a piece of paper, etc., as shown in Figure 10.4.

### Example 10.47

*Problem*

Find *I* when *E* = 120 V and *R* = 40 ohms (Ω).

*Solution*

Place your finger on *I* as shown in Figure 10.5. Use Equation 10.22 to find the unknown *I*.

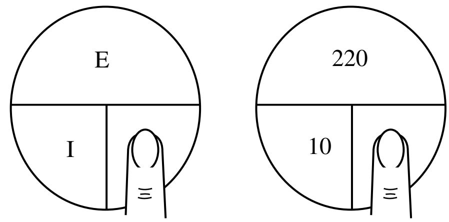


**FIGURE 10.6**

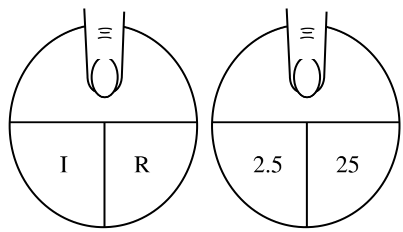


**FIGURE 10.7**

### Example 10.48

*Problem*

Find $R$ when $E = 220$ V and $I = 10$ A.

*Solution*

Place your finger on $R$ as shown in Figure 10.6. Use Equation 10.23 to find the unknown $R$.

### Example 10.49

*Problem*

Find $E$ when $I = 2.5$ A and $R = 25\ \Omega$.

*Solution*

Place your finger on E as shown in Figure 10.7.

$$E = IR = 2.5(25) = 62.5 \text{ V}$$

✔ **Note:** In the previous examples, we have demonstrated how the Ohm's law circle can help us solve simple voltage, current, and amperage problems. Beginning students are cautioned, however, not to rely entirely on the use of this circle when transposing simple formulae but rather to use it to supplement their knowledge of the algebraic method. Algebra is a basic tool in the solution of electrical problems, and its use should not be under-emphasized or bypassed after the operator has learned a shortcut method such as the one provided by this circle.

### Example 10.50

*Problem*

An electric light bulb draws 0.5 A when operating on a 120-V D-C circuit. What is the resistance of the bulb?

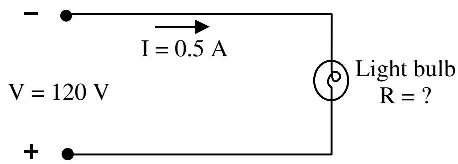


**FIGURE 10.8**

*Solution*

The first step in solving a circuit problem is to sketch a schematic diagram of the circuit itself, labeling each of the parts and showing the known values (see Figure 10.8). Because $E$ and $I$ are known, we use Equation 10.23 to solve for $R$.

$$R = \frac{E}{I} = \frac{120}{0.5} = 240\ \Omega$$

## Electric Power

*Power*, whether electrical or mechanical, pertains to the rate at which work is being done, so the power consumption in a plant is related to current flow. A large electric motor or air dryer consumes more power (and draws more current) in a given length of time than, for example, an indicating light on a motor controller. *Work* is done whenever a force causes motion. If a mechanical force is used to lift or move a weight, work is done; however, force exerted without causing motion, such as the force of a compressed spring acting between two fixed objects, does not constitute work.

✔ **Key Point:** Power is the rate at which work is done.

### Electrical Power Calculations

The electric power ($P$) used in any part of a circuit is equal to the current $I$ in that part multiplied by the voltage across that part of the circuit. In equation form:

$$P = EI \tag{10.25}$$

where

$P$ = power (W)
$E$ = voltage (V)
$I$ = current (A)

If we know current $I$ and resistance $R$ but not voltage $E$, we can find the power ($P$) by using Ohm's law for voltage. Substituting:

$$E = IR$$

$$P = IR \times I = I^2R \tag{10.26}$$

In the same manner, if we know the voltage ($E$) and the resistance ($R$) but not the current ($I$), we can find $P$ by using Ohm's law for current. Substituting:

$$I = \frac{E}{R}$$

$$P = E\frac{E}{R} = \frac{E^2}{R} \tag{10.27}$$

✓ **Key Point:** If we know any two quantities, we can calculate the third.

### Example 10.51

*Problem*

The current through a 200-Ω resistor to be used in a circuit is 0.25 A. Find the power rating of the resistor.

*Solution*

Because $R$ and $I$ are known, use Equation 10.26 to find $P$.

$$P = I^2R = (0.25)^2(200) = 0.0625(200) = 12.5 \text{ W}$$

### Example 10.52

*Problem*

How many kilowatts of power are delivered to a circuit by a 220-V generator that supplies 30 A to the circuit?

*Solution*

Because $E$ and $I$ are given, use Equation 10.25 to find $P$.

$$P = EI = 220(30) = 6600 \text{ W} = 6.6 \text{ kW}$$

### Example 10.53

*Problem*

If the voltage across a 30,000-Ω resistor is 450 V, what is the power dissipated in the resistor?

*Solution*

Because $R$ and $E$ are known, use Equation 10.27 to find $P$.

$$P = \frac{E^2}{R} = \frac{450^2}{30{,}000} = \frac{202{,}500}{30{,}000} = 6.75 \text{ W}$$

In this section, $P$ was expressed in terms of alternate pairs of the other three basic quantities $E$, $R$, and $I$. In practice, we should be able to express any one of the three basic quantities, as well as $P$, in terms of any two of the others. Figure 10.9 is a summary of 12 basic formulae you should know. The four quantities of $E$ (voltage), $I$ (amps), $R$ (resistance), and $P$ (power) are at the center of the figure. Adjacent to each quantity are three segments. Note that in each segment, the basic quantity is expressed in terms of two other basic quantities, and no two segments are alike.

## Electric Energy

*Energy* (the mechanical definition) is defined as the ability to do work (energy and time are essentially the same and are expressed in identical units). Energy is expended when work is done, because it takes energy to maintain a force when that force acts through a distance. The total energy expended to do a certain amount of work is equal to the working force multiplied by the distance through which the force is moved to do the work.

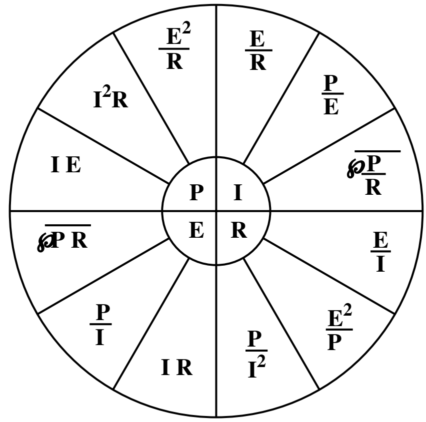


**FIGURE 10.9** Ohm's Law circle—Summary of Basic Formulae.

In electricity, total energy expended is equal to the *rate* at which work is done multiplied by the length of time the rate is measured. Essentially, energy ($W$) is equal to power ($P$) times time ($t$). The kilowatt-hour (kWh) is a unit commonly used for large amounts of electric energy or work. The amount of kilowatt-hours is calculated as the product of the power in kilowatts (kW) and the time in hours during which the power is used.

$$\text{kWh} = \text{kW} \times \text{hr} \tag{10.28}$$

### Example 10.54

*Problem*

How much energy is delivered in 4 hours by a generator supplying 12 kW?

*Solution*

$$\text{kWh} = \text{kW} \times \text{hr} = 12(4) = 48$$

The energy delivered is 48 kWh.

## Series D-C Circuit Characteristics

As previously mentioned, an electric circuit is made up of a voltage source, the necessary connecting conductors, and the effective load. If the circuit is arranged so that the electrons have only one possible path, the circuit is called a *series circuit*; therefore, a series circuit is defined as a circuit that contains only one path for current flow. Figure 10.10 shows a series circuit having several loads (resistors).

✔ **Key Point:** A *series circuit* is a circuit in which only one path exists for current to flow along.

### Resistance

Referring to Figure 10.10, the current in a series circuit, in completing its electrical path, must flow through each resistor inserted into the circuit. Thus, each additional resistor offers added resistance. In a series circuit, the total circuit resistance ($R_T$) is equal to the sum of the individual resistances:

$$R_T = R_1 + R_2 + R_3 + \ldots + R_n \tag{10.29}$$

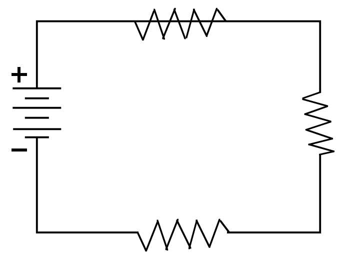

**FIGURE 10.10** Series circuit.

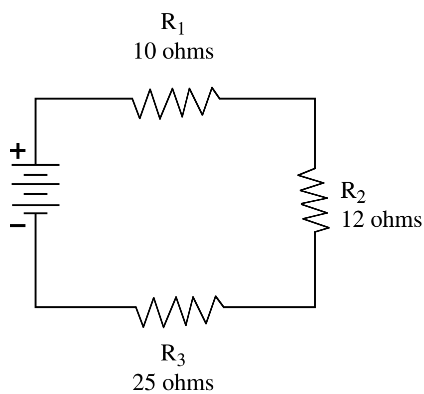


**FIGURE 10.11** Solving for total resistance in a series circuit.

where

$R_T$ = total resistance (Ω)
$R_1, R_2, R_3$ = resistance in series (Ω)
$R_n$ = any number of additional resistors in the equation

### Example 10.55

*Problem*

Three resistors of 10 ohms, 12 ohms, and 25 ohms are connected in series across a battery for which the emf is 110 volts (Figure 10.11). What is the total resistance?

*Solution*

$$R_1 = 10 \text{ ohms}$$

$$R_2 = 12 \text{ ohms}$$

$$R_3 = 25 \text{ ohms}$$

$$R_T = ?$$

$$R_T = R_1 + R_2 + R_3$$

$$R_T = 10 + 12 + 25$$

$$R_T = 47 \text{ ohms}$$

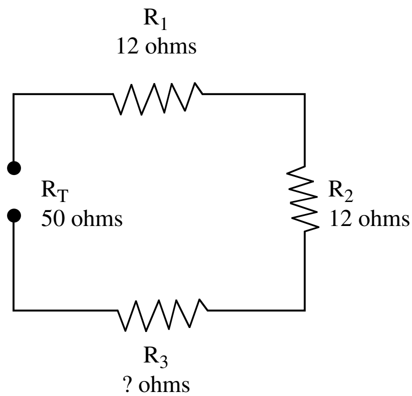


**FIGURE 10.12**

Equation 10.29 can be transposed to solve for the value of an unknown resistance. For example, transposition can be used in some circuit applications where the total resistance is known but the value of a circuit resistor has to be determined.

## Example 10.56

*Problem*

The total resistance of a circuit containing three resistors is 50 ohms (see Figure 10.12). Two of the circuit resistors are 12 ohms each. Calculate the value of the third resistor.

*Solution*

$$R_T = 50 \text{ ohms}$$

$$R_1 = 12 \text{ ohms}$$

$$R_2 = 12 \text{ ohms}$$

$$R_3 = ?$$

$$R_T = R_1 + R_2 + R_3$$

Subtracting $(R_1 + R_2)$ from both sides of the equation

$$R_3 = R_T - R_1 - R_2$$

$$R_3 = 50 - 12 - 12$$

$$R_3 = 50 - 24$$

$$R_3 = 26 \text{ ohms}$$

✔ **Key Point:** When resistances are connected in series, the total resistance in the circuit is equal to the sum of the resistances of all the parts of the circuit.

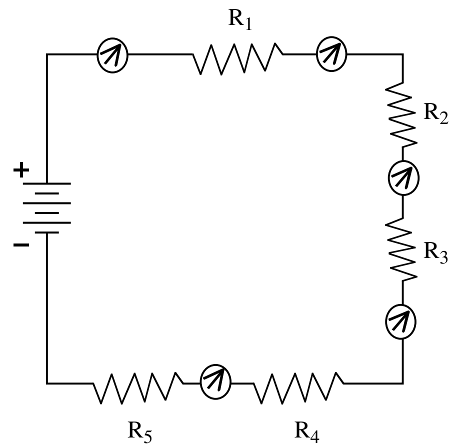


**FIGURE 10.13** Current in a series circuit.

## Current

Because there is but one path for current in a series circuit, the same current ($I$) must flow through each part of the circuit; thus, to determine the current throughout a series circuit, only the current through one of the parts need be known. The fact that the same current flows through each part of a series circuit can be verified by inserting ammeters into the circuit at various points as shown in Figure 10.13. As indicated in Figure 10.13, each meter indicates the same value of current.

✔ **Key Point:** In a series circuit, the same current flows in every part of the circuit. *Do not* add the currents in each part of the circuit to obtain $I$.

## Voltage

The *voltage* drop across the resistor in the basic circuit is the total voltage across the circuit and is equal to the applied voltage. The total voltage across a series circuit is also equal to the applied voltage but consists of the sum of two or more individual voltage drops. This statement can be proven by an examination of the circuit shown in Figure 10.14. In this circuit a source potential ($E_T$) of 30 V is impressed across a series circuit consisting of two 6-ohm resistors. The total resistance of the circuit is equal to the sum of the two individual resistances, or 12 ohms. Using Ohm's law, the circuit current may be calculated as follows:

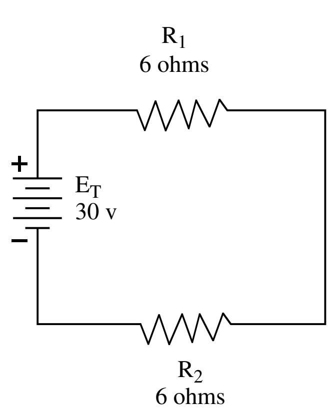


**FIGURE 10.14** Calculating total resistance in a series circuit.

$$I = \frac{E_T}{R_T}$$

$$I = \frac{30}{12}$$

$$I = 2.5 \text{ amperes}$$

Knowing that the value of the resistors is 6 ohms each and the current through the resistors is 2.5 amperes, the voltage drops across the resistors can be calculated. The voltage ($E_1$) across $R_1$ is, therefore:

$$E_1 = IR_1$$

$$E_1 = 2.5 \text{ amps} \times 6 \text{ ohms}$$

$$E_1 = 15 \text{ volts}$$

Because $R_2$ is the same ohmic value as $R_1$ and carries the same current, the voltage drop across $R_2$ is also equal to 15 volts. Adding these two 15-volt drops together gives a total drop of 30 volts, exactly equal to the applied voltage. For a series circuit then:

$$E_T = E_1 + E_2 + E_3 + \ldots + E_n \tag{10.30}$$

where

$E_T$ = total voltage (V)
$E_1$ = voltage across resistance $R_1$ (V)
$E_2$ = voltage across resistance $R_2$ (V)
$E_3$ = voltage across resistance $R_3$ (V)

**Example 10.57**

*Problem*

A series circuit consists of three resistors having values of 10, 20, and 40 ohms, respectively. Find the applied voltage if the current through the 20-ohm resistor is 2.5 amperes.

*Solution*

To solve this problem, a circuit diagram is first drawn and labeled as shown in Figure 10.15.

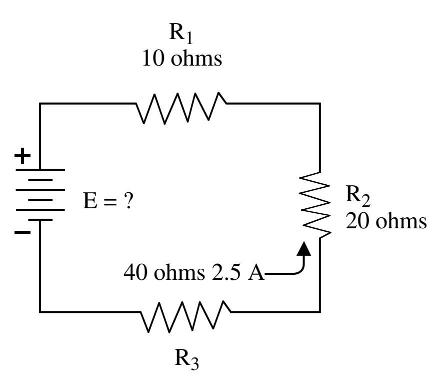


**FIGURE 10.15** Solving for applied voltage in a series circuit.

$$R_1 = 10 \text{ ohms}$$

$$R_2 = 20 \text{ ohms}$$

$$R_3 = 40 \text{ ohms}$$

$$I = 2.5 \text{ amps}$$

Because the circuit involved is a series circuit, the same 2.5 amperes of current flows through each resistor. Using Ohm's law, the voltage drops across each of the three resistors can be calculated:

$$E_1 = 25 \text{ volts}$$

$$E_2 = 50 \text{ volts}$$

$$E_3 = 100 \text{ volts}$$

Once the individual drops are known, they can be added to find the total or applied voltage using Equation 10.30:

$$E_T = E_1 + E_2 + E_3$$

$$E_T = 25 \text{ V} + 50 \text{ V} + 100 \text{ V}$$

$$E_T = 175 \text{ volts}$$

✓ **Key Point 1:** The total voltage ($E_T$) across a series circuit is equal to the sum of the voltages across each resistance of the circuit.

✓ **Key Point 2:** The voltage drops that occur in a series circuit are in direct proportions to the resistance across which they appear. This is the result of having the same current flow through each resistor. Thus, the larger the resistor, the larger will be the voltage drop across it.

## Power

Each resistor in a series circuit consumes *power*. This power is dissipated in the form of heat. Because this power must come from the source, the total power must be equal in amount to the power consumed by the circuit resistances. In a series circuit, the total power is equal to the *sum* of the powers dissipated by the individual resistors. Total power ($P_T$) is thus equal to:

$$P_T = P_1 + P_2 + P_3 + \ldots + P_n \tag{10.31}$$

where

$P_T$ = total power (W)
$P_1$ = power used in first part (W)
$P_2$ = power used in second part (W)
$P_3$ = power used in third part (W)
$P_n$ = power used in $n$th part (W)

## Example 10.58

### *Problem*

A series circuit consists of three resistors having values of 5, 15, and 20 ohms. Find the total power dissipation when 120 volts is applied to the circuit (see Figure 10.16).

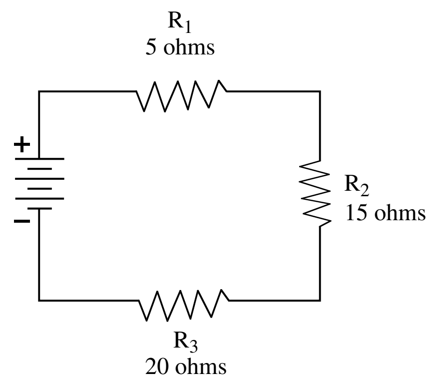


**FIGURE 10.16** Solving for total power in a series circuit.

*Solution*

$$R_1 = 5 \text{ ohms}$$

$$R_2 = 15 \text{ ohms}$$

$$R_3 = 20 \text{ ohms}$$

$$E = 120 \text{ volts}$$

The total resistance is found first.

$$R_\mathrm{T} = R_1 + R_2 + R_3$$

$$R_T = 5 + 15 + 20$$

$$R_T = 40 \text{ ohms}$$

Using total resistance and the applied voltage, the circuit current is calculated.

$$I = \frac{E_T}{R_T}$$

$$I = \frac{120}{40}$$

$$I = 3 \text{ amps}$$

Using the power formula, the individual power dissipations can be calculated.

- For resistor $R_1$:

$$P_1 = I^2 R_1$$

$$P_1 = (3)^2 5$$

$$P_1 = 45 \text{ watts}$$

- For $R_2$:

$$P_2 = I^2R_2$$

$$P_2 = (3)^2 15$$

$$P_2 = 135 \text{ watts}$$

- For $R_3$:

$$P_3 = I^2R_3$$

$$P_3 = (3)^2 20$$

$$P_3 = 180 \text{ watts}$$

To obtain total power:

$$P_T = P_1 + P_2 + P_3$$

$$P_T = 45 + 135 + 180$$

$$P_T = 360 \text{ watts}$$

To check the answer the total power delivered by the source can be calculated:

$$P = E \text{ x } I$$

$$P = 3 \text{ A} \times 120 \text{ V}$$

$$P = 360 \text{ watts}$$

Thus, the total power is equal to the sum of the individual power dissipations.

> ✓ **Key Point:** We found that Ohm's law can be used for total values in a series circuit as well as for individual parts of the circuit. Similarly, the formula for power may be used for total values.
>
> $$P_T = IE_T$$

## General Series Circuit Analysis

Now that we have discussed the pieces involved in putting together the puzzle for solving series circuit analysis, we move on to the next step in the process: solving series circuit analysis in total.

## Example 10.59

### *Problem*

Three resistors of 20, 20, and 30 ohms are connected across a battery supply rated at 100-volt terminal voltage. Completely solve the circuit shown in Figure 10.17.

> ✓ **Note:** To solve the circuit, the total resistance is found first. Next, the circuit current will be calculated. Once the current is known, the voltage drops and power dissipations can be calculated.

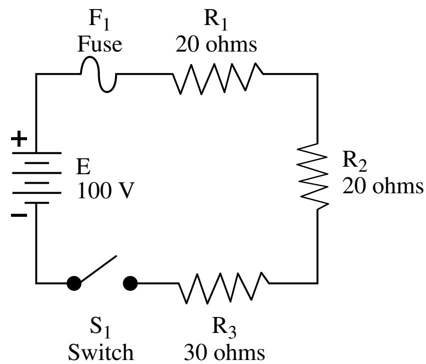


**FIGURE 10.17** Solving for various values in a series circuit.

*Solution*

The total resistance is:

$$R_T = R_1 + R_2 + R_3$$

$$R_T = 20 \text{ ohms} + 20 \text{ ohms} + 30 \text{ ohms}$$

$$R_T = 70 \text{ ohms}$$

By Ohm's law the current is:

$$I = \frac{E}{R_T}$$

$$I = \frac{100}{70}$$

$$I = 1.43 \text{ amps (rounded)}$$

The voltage ($E_1$) across $R_1$ is:

$$E_1 = IR_1$$

$$E_1 = 1.43 \text{ amps} \times 20 \text{ ohms}$$

$$E_1 = 28.6 \text{ volts}$$

The voltage ($E_2$) across $R_2$ is:

$$E_2 = \mathrm{I}R_2$$

$$E_2 = 1.43 \text{ amps} \times 20 \text{ ohms}$$

$$E_2 = 28.6 \text{ volts}$$

The voltage ($E_3$) across $R_3$ is:

$$E_3 = IR_2$$

$$E_3 = 1.43 \text{ amps} \times 30 \text{ ohms}$$

$$E_3 = 42.9 \text{ volts}$$

The power dissipated by $R_1$ is:

$$P_1 = \mathrm{I} \times E_1$$

$$P_1 = 1.43 \text{ amps} \times 28.6 \text{ volts}$$

$$P_1 = 40.9 \text{ watts}$$

The power dissipated by $R_2$ is:

$$P_2 = \mathrm{I} \times E_2$$

$$P_2 = 1.43 \text{ amps} \times 28.6 \text{ volts}$$

$$P_2 = 40.9 \text{ watts}$$

The power dissipated by $R_3$ is:

$$P_3 = I \times E_3$$

$$P_3 = 1.43 \text{ amps} \times 42.9 \text{ volts}$$

$$P_3 = 61.3 \text{ watts (rounded)}$$

The total power dissipated is:

$$P_T = E_T \times \mathrm{I}$$

$$P_T = 100 \text{ volts} \times 1.43 \text{ amps}$$

$$P_T = 143 \text{ watts}$$

✔ **Important Note:** Keep in mind when applying Ohm's law to a series circuit to consider whether the values used are component values or total values. When the information available enables the use of Ohm's law to find total resistance, total voltage, and total current, total values must be inserted into the formula.

To find total resistance:

$$R_T = \frac{E_T}{I_T}$$

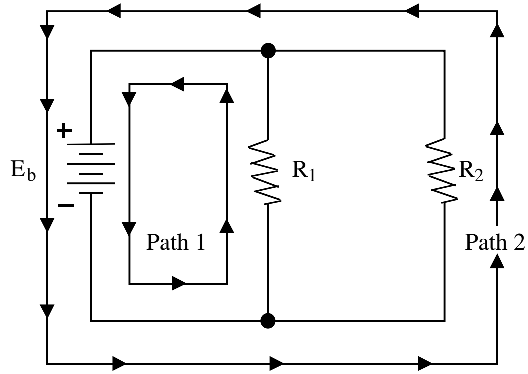


**FIGURE 10.18** Basic parallel circuit.

To find total voltage:

$$E_T = I_T \times R_T$$

To find total current:

$$I_T = \frac{E_T}{R_T}$$

## Parallel D-C Circuits

The principles we applied to solving simple series circuit calculations for determining the reactions of such quantities as voltage, current, and resistance also can be used in parallel and series–parallel circuits.

### Parallel Circuit Characteristics

A *parallel circuit* is defined as one having two or more components connected across the same voltage source (see Figure 10.18). Recall that a series circuit has only one path for current flow. As additional loads (resistors, etc.) are added to the circuit, the total resistance increases and the total current decreases. This is *not the case* in a parallel circuit. In a parallel circuit, each load (or branch) is connected directly across the voltage source. In Figure 10.18, commencing at the voltage source ($E_b$) and tracing counterclockwise around the circuit, two complete and separate paths can be identified in which current can flow. One path is traced from the source through resistance $R_1$ and back to the source; the other, from the source through resistance $R_2$ and back to the source.

### Voltage in Parallel Circuits

Recall that in a series circuit the source voltage divides proportionately across each resistor in the circuit. In a parallel circuit (see Figure 10.18), the same voltage is present across all the resistors of a parallel group. This voltage is equal to the applied voltage ($E_b$) and can be expressed in equation form as:

$$E_b = E_{R1} = E_{R2} = E_{Rn} \tag{10.32}$$

We can verify Equation 10.32 by taking voltage measurements across the resistors of a parallel circuit, as illustrated in Figure 10.19. Notice that each voltmeter indicates the same amount of voltage; that is, the voltage across each resistor is the same as the applied voltage.

✔ **Key Point:** In a parallel circuit, the voltage remains the same throughout the circuit.

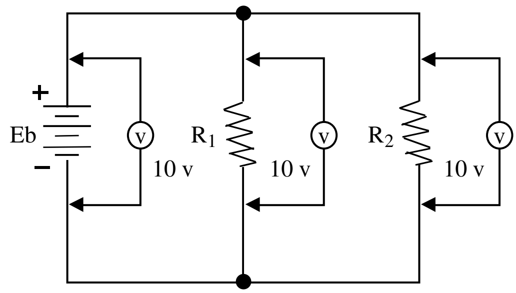


**FIGURE 10.19** Voltage comparison in a parallel circuit.

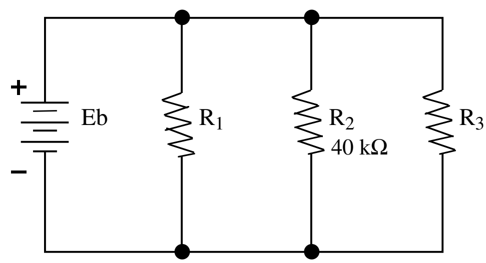


**FIGURE 10.20** Refers to Example 10.60.

## Example 10.60

*Problem*

Assume that the current through a resistor of a parallel circuit is known to be 4.0 milliamperes (mA) and the value of the resistor is 40,000 ohms. Determine the potential (voltage) across the resistor. The circuit is shown in Figure 10.20.

*Solution*

$$R_2 = 40 \text{ k}\Omega$$

$$I_{R2} = 4.0 \text{ mA}$$

Find:

$$E_{R2} = ?$$

$$E_b = ?$$

Select the proper equation:

$$E = IR$$

Substitute known values:

$$E_{R2} = I_{R2} \times R_2$$

$$E_{R2} = 4.0 \text{ mA} \times 40{,}000 \text{ ohms}$$

[Use power of tens.]

$$E_{R2} = (4.0 \times 10^{-3}) \times (40 \times 10^3)$$

$$E_{R2} = 4.0 \times 40$$

Resultant:

$$E_{R2} = 160 \text{ V}$$

Therefore:

$$E_b = 160 \text{ V}$$

## Current in Parallel Circuits

**Important Point:** Ohm's Law states that the current in a circuit is inversely proportional to the circuit resistance. This fact, important as a basic building block of electrical theory, obviously is also important in the following explanation of current flow in parallel circuits.

In a series circuit, a single current flows. Its value is determined in part by the total resistance of the circuit; however, the source current in a parallel circuit divides among the available paths in relation to the value of the resistors in the circuit. Ohm's law remains unchanged. For a given voltage, current varies inversely with resistance. The behavior of current in a parallel circuit is best illustrated by example. The example we use is Figure 10.21. The resistors $R_1$, $R_2$, and $R_3$ are in parallel with each other and with the battery. Each parallel path is then a branch with its own individual current. When the total current $I_T$ leaves the voltage source $E$, part $I_1$ of the current $I_T$ will flow through $R_1$, part $I_2$ will flow through $R_2$, and the remainder ($I_3$) will flow through $R_3$. The branch currents $I_1$, $I_2$, and $I_3$ can be different; however, if a voltmeter (used for measuring the voltage of a circuit) is connected across $R_1$, $R_2$, and $R_3$, the respective voltages $E_1$, $E_2$, and $E_3$ will be equal. Therefore,

$$E = E_1 = E_2 = E_3$$

The total current ($I_T$) is equal to the sum of all branch currents:

$$I_T = I_1 = I_2 = I_3 \tag{10.33}$$

This formula applies for any number of parallel branches whether the resistances are equal or unequal.

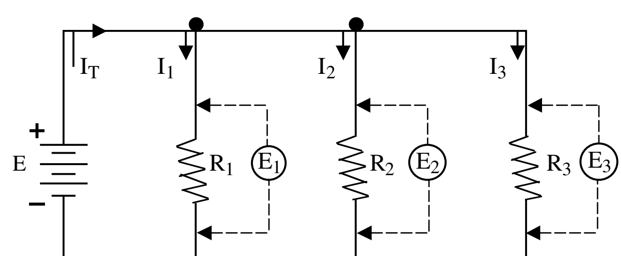


**FIGURE 10.21** Parallel circuit.

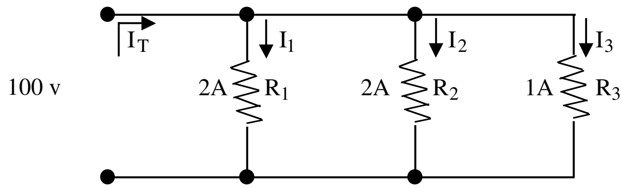


**FIGURE 10.22** Refers to Example 10.61.

By Ohm's law, each branch current equals the applied voltage divided by the resistance between the two points where the voltage is applied. Hence, for each branch we have the following equations (Figure 10.21):

$$
\begin{aligned}
&\text{Branch 1:} \quad I_1 = \frac{E_1}{R_1} = \frac{E}{R_1} \\
&\text{Branch 2:} \quad I_2 = \frac{E_2}{R_2} = \frac{E}{R_2} \\
&\text{Branch 3:} \quad I_3 = \frac{E_3}{R_3} = \frac{V}{R_3}
\end{aligned}
\tag{10.34}
$$

With the same applied voltage, any branch that has less resistance allows more current through it than a branch with higher resistance.

### Example 10.61

*Problem*

Two resistors each drawing 2 A and a third resistor drawing 1 A are connected in parallel across a 100-V line (see Figure 10.22). What is the total current?

*Solution*

The formula for total current is:

$$
\begin{aligned}
I_T &= I_1 + I_2 + I_3 \\
&= 2 + 2 + 1 \\
&= 5\ \text{A}
\end{aligned}
\tag{10.35}
$$

The total current is 5 A.

### Example 10.62

*Problem*

Two branches ($R_1$ and $R_2$) across a 100-V power line draw a total line current of 20 A (Figure 10.23). Branch $R_1$ takes 10 A. What is the current $I_2$ in branch $R_2$?

*Solution*

Starting with Equation 10.35, transpose to find $I_2$ and then substitute the given values.

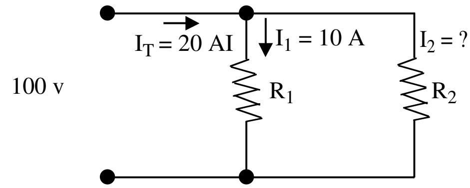


**FIGURE 10.23** Refers to Example 10.62.

$$I_T = I_1 + I_2$$

$$I_2 = I_T - I_1$$

$$= 20 - 10 = 10 \text{ A}$$

The current in branch $R_2$ is 10 A.

## Example 10.63

*Problem*

A parallel circuit consists of two 15-ohm and one 12-ohm resistor across a 120-V line (see Figure 10.24). What current will flow in each branch of the circuit and what is the total current drawn by all the resistors?

*Solution*

Across each resistor is a 120-V potential.

$$I_1 = \frac{V}{R_1} = \frac{120}{15} = 8 \text{ A}$$

$$I_2 = \frac{V}{R_2} = \frac{120}{15} = 8 \text{ A}$$

$$I_3 = \frac{V}{R_3} = \frac{120}{12} = 10 \text{ A}$$

Now find the total current:

$$I_T = I_1 + I_2 + I_3$$

$$= 8 + 8 + 10 = 26 \text{ A}$$

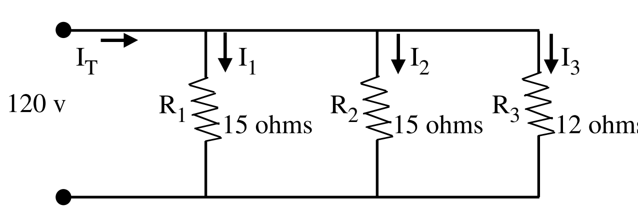


**FIGURE 10.24** Refers to Example 10.63.

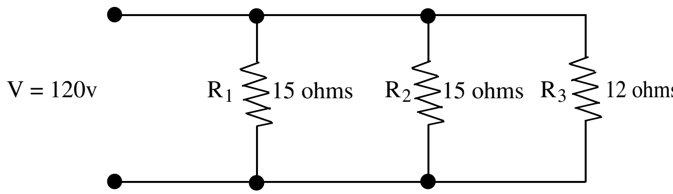


**FIGURE 10.25** Refers to Example 10.64.

## Parallel Resistance

Unlike series circuits where total resistance ($R_T$) is the sum of the individual resistances, in a parallel circuit the total resistance is *not* the sum of the individual resistances. In a parallel circuit we can use Ohm's law to find the total resistance. We use the equation:

$$R = \frac{E}{I}$$

or

$$R_T = \frac{E_s}{I_T}$$

where $R_T$ is the total resistance of all the parallel branches across the voltage source $E_S$, and $I_T$ is the sum of all the branch currents.

### Example 10.64

*Problem*

What is the total resistance of the circuit shown in Figure 10.25?

$$E_5 = 120 \text{ V}$$

$$I_T = 26 \text{ A}$$

*Solution*

In Figure 10.25 the line voltage is 120 V and the total line current is 26 A. Therefore,

$$R_T = \frac{E}{I_T} = \frac{120}{26} = 4.62 \text{ ohms}$$

Other methods are used to determine the equivalent resistance of parallel circuits. The most appropriate method for a particular circuit depends on the number and value of the resistors. For example, consider the parallel circuit shown in Figure 10.26. For this circuit, the following simple equation is used:

$$R_{eq} = \frac{R}{N} \tag{10.36}$$

where

$R_{eq}$ = equivalent parallel resistance
$R$ = ohmic value of one resistor
$N$ = number of resistors

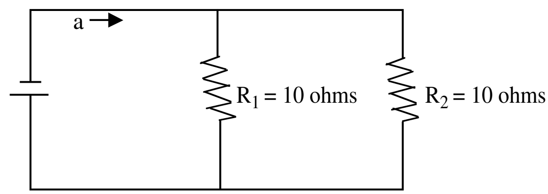


**FIGURE 10.26** Two equal resistors connected in parallel.

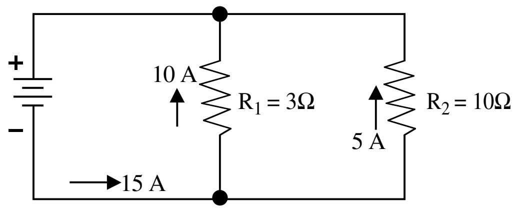


**FIGURE 10.27** Refers to Example 10.66.

Thus,

$$R_{eq} = \frac{10 \text{ ohms}}{2}$$

$$R_{eq} = 5 \text{ ohms}$$

✔ **Key Point:** When two equal value resistors are connected in parallel, they present a total resistance equivalent to a single resistor of one half the value of either of the original resistors.

## Example 10.65

*Problem*

Five 50-ohm resistors are connected in parallel. What is the equivalent circuit resistance?

*Solution*

$$R_{eq} = \frac{R}{N} = \frac{50}{5} = 10 \text{ ohms}$$

What about parallel circuits containing resistance of unequal value? How is equivalent resistance determined?

## Example 10.66

*Problem*

Refer to Figure 10.27.

*Solution*

$$R_1 = 3\ \Omega$$

$$R_2 = 6\ \Omega$$

$$E_a = 30 \text{ V}$$

Known:

$$I_1 = 10 \text{ amps}$$

$$I_2 = 5 \text{ amps}$$

$$I_T = 15 \text{ amps}$$

Determine:

$$R_{eq} = ?$$

$$R_{eq} = \frac{E_a}{I_T}$$

$$R_{eq} = \frac{30}{15} = 2 \text{ ohms}$$

### The Reciprocal Method

When circuits are encountered in which resistors of unequal value are connected in parallel, the equivalent resistance may be computed by using the *reciprocal method*.

> ✓ **Note:** A *reciprocal* is an inverted fraction; the reciprocal of the fraction 3/4, for example, is 4/3. We consider a whole number to be a fraction with 1 as the denominator, so the reciprocal of a whole number is that number divided into 1. For example, the reciprocal of $R_T$ is $1/R_T$. The equivalent resistance in parallel is given by the formula:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + + \frac{1}{R_n}$$

where $R_T$ is the total resistance in parallel, and $R_1$, $R_2$, $R_3$, and $R_n$ are the branch resistances.

### Example 10.67

*Problem*

Find the total resistance of a 2, 4, and 8-ohm resistor in parallel (Figure 10.28).

*Solution*

Write the formula for three resistors in parallel:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

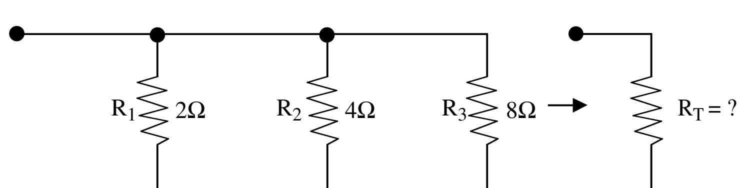


**FIGURE 10.28** Refers to Example 10.67.

Substituting the resistance values.

$$\frac{1}{R_T} = \frac{1}{2} + \frac{1}{4} + \frac{1}{8}$$

Add fractions:

$$\frac{1}{R_T} = \frac{4}{8} + \frac{2}{8} + \frac{1}{8} = \frac{7}{8}$$

Invert both sides of the equation to solve for $R_T$:

$$R_T = \frac{8}{7} = 1.14\ \Omega$$

> ✓ **Note:** When resistances are connected in parallel, the total resistance is always *less* than the smallest resistance of any single branch.

### Product Over the Sum Method

When any two unequal resistors are in parallel, it is often easier to calculate the total resistance by multiplying the two resistances and then dividing the product by the sum of the resistances:

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2} \tag{10.38}$$

where $R_T$ is the total resistance in parallel, and $R_1$ and $R_2$ are the two resistors in parallel.

### Example 10.68

*Problem*

What is the equivalent resistance of a 20-ohm and a 30-ohm resistor connected in parallel?

*Solution*

$$R_1 = 20$$

$$R_2 = 30$$

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$R_T = \frac{20 \times 30}{20 + 30}$$

$$R_T = 12 \text{ ohms}$$

### Power in Parallel Circuits

As in the series circuit, the total power consumed in a parallel circuit is equal to the sum of the power consumed in the individual resistors.

> ✓ **Note:** Because power dissipation in resistors consists of a heat loss, power dissipations are additive regardless of how the resistors are connected in the circuit.

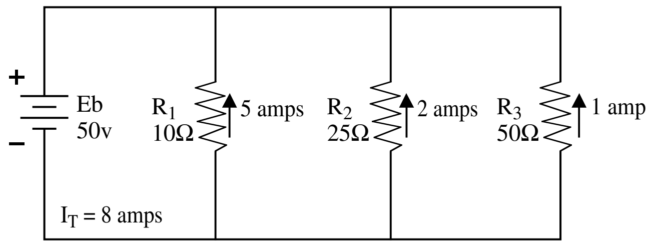


**FIGURE 10.29** Refers to Example 10.69.

$$P_T = P_1 + P_2 + P_3 + \ldots + P_n$$

where $P_T$ is the total power, and $P_1$, $P_2$, $P_3$, and $P_n$ are the branch powers. Total power can also be calculated by the equation:

$$P_{\mathrm{T}} = EI_T$$

where $P_T$ is the total power, $E$ is the voltage source across all parallel branches, and $I_T$ is the total current. The power dissipated in each branch is equal to $EI$ and is equal to $E^2/R$.

> ✓ **Note:** In both parallel and series arrangements, the sum of the individual values of power dissipated in the circuit equals the total power generated by the source. The circuit arrangements cannot change the fact that all power in the circuit comes from the source.

## Example 10.69

*Problem*

Find the total power consumed by the circuit in Figure 10.29.

*Solution*

$$P_{R1} = E_b \times I_{R1}$$

$$P_{R1} = 50 \times 5$$

$$P_{R1} = 250 \text{ watts}$$

$$P_{R2} = E_{\mathrm{b}} \times I_{R2}$$

$$P_{R2} = 50 \times 2$$

$$P_{R2} = 100 \text{ watts}$$

$$P_{R3} = E_b \times I_{R3}$$

$$P_{R3} = 50 \times 1$$

$$P_{R3} = 50 \text{ watts}$$

$$P_T = P_1 + P_2 + P_3$$

$$P_T = 250 + 100 + 50$$

$$P_T = 400 \text{ watts}$$

Because, in the example shown in Figure 10.29, the total current is known, we could determine the total power by the following method:

$$P_T = E_b \times I_T$$

$$P_T = 50 \text{ V} \times 8 \text{ A}$$

$$P_T = 400 \text{ watts}$$

# 11 Measurements: Circumference, Area, and Volume

**TOPICS**



Water/wastewater treatment plants consist of a series of tanks and channels. Proper operational control requires the operator to perform several process control calculations involving parameters such as the circumference, perimeter, area, or volume of a tank or channel. Many process calculations require computation of surface areas. To aid in performing these calculations, the following definitions are provided:

- *Area* — Area of an object, measured in square units.
- *Base* — Term used to identity the bottom leg of a triangle, measured in linear units.
- *Circumference* — Distance around an object, measured in linear units. When determined for other than circles, it may be called the perimeter of the figure, object, or landscape.
- *Cubic units* — Measurements used to express volume, cubic feet, cubic meters, etc.
- *Depth* — Vertical distance from the bottom the tank to the top; normally measured in terms of liquid depth and given in terms of sidewall depth (SWD), measured in linear units.
- *Diameter* — Distance from one edge of a circle to the opposite edge, passing through the center; measured in linear units.
- *Height* — Vertical distance from one end of an object to the other, measured in linear units.
- *Length* — Distance from one end of an object to the other, measured in linear units.
- *Linear units* — Measurements used to express distances such as feet, inches, meters, yards, etc.
- *Pi* ($\pi$) — Number in the calculations involving circles, spheres, or cones ($\pi$ = 3.14).
- *Radius* — Distance from the center of a circle to the edge, measured in linear units.

- *Sphere* — Container shaped like a ball.
- *Square units* — Measurements used to express area, square feet, square meters, acres, etc.
- *Volume* — Capacity of the unit, or how much it will hold; measured in cubic units (cubic feet, cubic meters) or in liquid volume units (gallons, liters, million gallons).
- *Width* — Distance from one side of the tank to the other, measured in linear units.

## PERIMETER AND CIRCUMFERENCE

On occasion, it may be necessary to determine the distance around grounds or landscapes. In order to measure the distance around property, buildings, and basin-like structures, it is necessary to determine either perimeter or circumference. The *perimeter* is the distance around an object and can be considered a border or outer boundary. *Circumference* is the distance around a circle or circular object, such as a clarifier. Distance is linear measurement, which defines the distance (or length) along a line. Standard units of measurement such as inches, feet, yards, and miles and metric units such as centimeters, meters, and kilometers are used.

### PERIMETER

The *perimeter* of a rectangle (a four-sided figure with four right angles) is obtained by adding the lengths of the four sides (see Figure 11.1).

$$\text{Perimeter } (P) = L_1 + L_2 + L_3 + L_4 \tag{11.1}$$

**Example 11.1**

*Problem*

Find the perimeter of the rectangle shown in Figure 11.2.

*Solution*

$$P = 35' + 8' + 35' + 8'$$

$$P = 86'$$

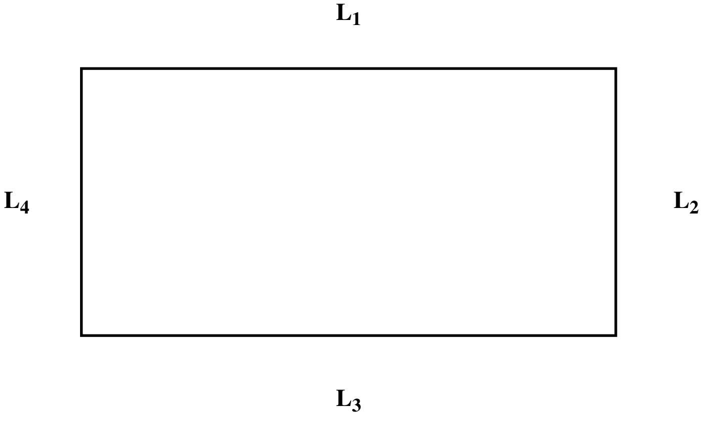


**FIGURE 11.1** Perimeter.

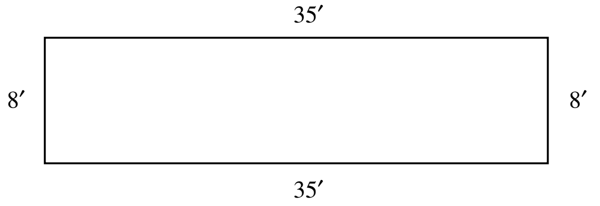


**FIGURE 11.2** Perimeter of a rectangle.

### Example 11.2

*Problem*

What is the perimeter of a rectangular field if its length is 100 feet and its width is 50 feet?

*Solution*

$$\begin{aligned}\text{Perimeter} &= 2(\text{length}) + 2(\text{width})\\ &= 2 \times 100 \text{ ft} + 2 \times 50 \text{ ft}\\ &= 200 \text{ ft} + 100 \text{ ft}\\ &= 300 \text{ ft}\end{aligned}$$

### Example 11.3

*Problem*

What is the perimeter of a square with 8-inch sides?

*Solution*

$$\begin{aligned}\text{Perimeter} &= 2(\text{length}) + 2(\text{width})\\ &= 2 \times 8 \text{ in.} + 2 \times 8 \text{ in.}\\ &= 16 \text{ in.} + 16 \text{ in.}\\ &= 32 \text{ in.}\end{aligned}$$

## Circumference

The *circumference* ($C$) is the length of the outer border of a circle. The circumference is found by multiplying pi ($\pi$) times the *diameter* ($D$) (diameter is the length of a straight line passing through the center of a circle; see Figure 11.3).

$$C = \pi D \tag{11.2}$$

where

$C$ = circumference
$\pi$ = Greek letter pi = 3.1416
$D$ = diameter

Use this calculation if, for example, the circumference of a circular tank must be determined.

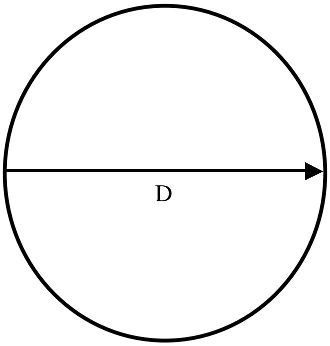


**FIGURE 11.3** Circumference.

### Example 11.4

*Problem*

Find the circumference of a circle that has a diameter of 25 feet ($\pi = 3.14$).

*Solution*

$$C = \pi \times 25'$$

$$C = 3.14 \times 25'$$

$$C = 78.5'$$

### Example 11.5

*Problem*

A circular chemical holding tank has a diameter of 18 m. What is the circumference of this tank?

*Solution*

$$C = \pi \times 18 \text{ m}$$

$$C = 3.14 \times 18 \text{ m}$$

$$C = 56.52 \text{ m}$$

### Example 11.6

*Problem*

An influent pipe inlet opening has a diameter of 6 feet. What is the circumference of the inlet opening in inches?

*Solution*

$$C = \pi \times 6'$$

$$C = 3.14 \times 6'$$

$$C = 18.84'$$

## AREA

For area measurements in water/wastewater operations, three basic shapes are particularly important: circles, rectangles, and triangles. *Area* is a measure of the surface an object or, put another way, the amount of material required to cover the surface. The area on top of a chemical tank is called the *surface area*. The area of the end of a ventilation duct is called the *cross-sectional area* (the area at right angles to the length of ducting). Area is usually expressed in square units, such as square inches (in.$^2$) or square feet (ft$^2$). Land may also be expressed in terms of square miles (sections) or acres (43,560 ft$^2$) or, in the metric system, as *hectares.*

### Area of a Rectangle

A *rectangle* is a two-dimensional box. The area of a rectangle is found by multiplying the length ($L$) times width ($W$); see Figure 11.4.

$$\text{Area} = L \times W \tag{11.3}$$

#### Example 11.7

*Problem*

Find the area of the rectangle shown in Figure 11.5.

*Solution*

$$\begin{aligned}\text{Area} &= L \times W\\ &= 14' \times 6'\\ &= 84 \text{ ft}^2\end{aligned}$$

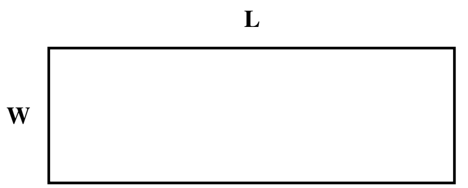


**FIGURE 11.4** Area of a rectangle.

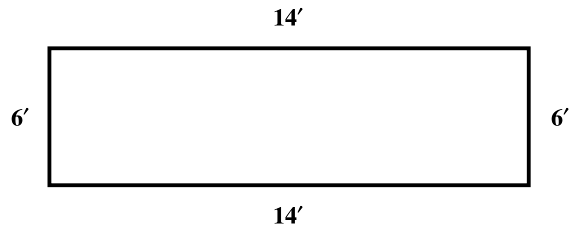


**FIGURE 11.5** Refers to Example 11.7.

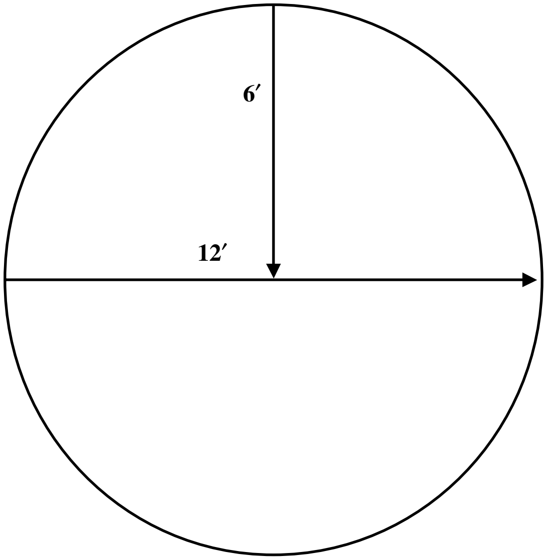


**FIGURE 11.6** Area of a circle.

## AREA OF A CIRCLE

To find the area of a circle, we must introduce a new term, the *radius* ($r$). In Figure 11.6, the circle has a radius of 5 inches. The radius is any straight line that radiates from the center of the circle to some point on the circumference. By definition, all radii (plural of radius) of the same circle are equal. The surface area of a circle is determined by multiplying π times the radius squared:

$$\text{Area of circle} = \pi r^2 \tag{11.4}$$

where

$A$ = area
$\pi$ = pi (3.14)
$r$ = radius of circle (radius is one half the diameter)

### Example 11.8

*Problem*

What is the area of the circle shown in Figure 11.6?

$$\begin{aligned}\text{Area of circle} &= \pi r^2 \\ &= \pi 6^2 \\ &= 3.14 \times 36 \\ &= 113 \text{ ft}^2\end{aligned}$$

## SURFACE AREA OF A CIRCULAR OR CYLINDRICAL TANK

If we were assigned to paint a water storage tank, we must know the surface area of the walls of the tank to determine how much paint is required. To determine the surface area of the tank, we can visualize the cylindrical walls as a rectangle wrapped around a circular base. The area of a rectangle is found by multiplying the length by the width; in this case, the width of the rectangle

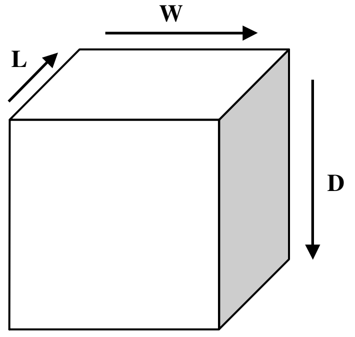


**FIGURE 11.7** Volume.

is the height of the wall, and the length of the rectangle is the distance around the circle, the circumference. Thus, the area of the side walls of the circular tank is found by multiplying the circumference of the base ($C = \pi \times D$) times the height of the wall ($H$):

$$\text{Area } (A) = \pi \times \text{Diameter } (D) \times \text{Height } (H) \tag{11.5}$$

$$A = \pi \times 20 \text{ ft} \times 25 \text{ ft}$$

$$A = 3.14 \times 20 \text{ ft} \times 25 \text{ ft}$$

$$A = 1570.8 \text{ ft}^2$$

To determine the amount of paint required, remember to add the surface area of the top of the tank, which is 314 $\text{ft}^2$; thus, we must have enough paint to cover 1570.8 $\text{ft}^2$ + 314 $\text{ft}^2$ = 1884.8, or 1885 $\text{ft}^2$. If the tank floor should be painted, add another 314 $\text{ft}^2$.

## VOLUME

*Volume* is the amount of space occupied by or contained in an object (see Figure 11.7) and is expressed in cubic units, such as cubic inches ($\text{in.}^3$), cubic feet ($\text{ft}^3$), acre feet (1 acre foot = 43,560 $\text{ft}^3$), etc.

### VOLUME OF A RECTANGULAR BASIN

The volume of a rectangular object is obtained by multiplying the length times the width times the depth or height.

$$V = L \times W \times H \tag{11.6}$$

where

$L$ = length
$W$ = width
$D$ or $H$ = depth or height

### Example 11.9

*Problem*

A unit rectangular process basin has a length of 15′, width of 7′, and depth of 9′. What is the volume of the basin?

**TABLE 11.1**
**Volume Formulae**

| | |
|---|---|
| Sphere volume | = ($\pi$/6)(Diameter)$^3$ |
| Cone volume | = (1/3)(Volume of a cylinder) |
| Rectangular tank volume | = (Area of rectangle) ($D$ or $H$) |
| | = ($LW$) ($D$ or $H$) |
| Cylinder volume | = (Area of cylinder) ($D$ or $H$) |
| | = $\pi^2$ ($D$ or $H$) |
| Triangle volume | = (Area of triangle) ($D$ or $H$) |
| | = (bh/2)($D$ or $H$) |

*Solution*

$$V = L \times W \times D$$

$$= 15' \times 7' \times 9'$$

$$= 954 \text{ ft}^3$$

For water/wastewater operators, representative surface areas are most often rectangles, triangles, circles, or a combination of these shapes. Practical volume formulae used in water/wastewater calculations are given in Table 11.1.

## Volume of Round Pipe and Round Surface Areas

### Example 11.10

*Problem*

Find the volume of a 3-in. round pipe that is 300 ft long.

*Solution*

- Step 1: Change the diameter (D) of the duct from inches to feet by dividing by 12.

$$D = 3 \div 12 = 0.25 \text{ ft}$$

- Step 2: Find the radius ($r$) by dividing the diameter by 2.

$$r = 0.25 \text{ ft} \div 2 = 0.125$$

- Step 3: Find the volume ($V$).

$$V = L \times \pi r^2$$

$$V = 300 \text{ ft} \times 3.14 \times 0.312$$

$$V = 14.70 \text{ ft}^2$$

**Example 11.11**

*Problem*

Find the volume of a smokestack that is 24 in. in diameter (entire length) and 96 in. tall. Find the radius ($r$) of the stack. The radius is one half the diameter. Find the volume ($V$).

$$r = 24 \text{ in.} \div 2 = 12 \text{ in.}$$

*Solution*

$$V = \text{H} \times \pi r^2$$

$$V = 96 \text{ in.} \times \pi(12 \text{ in.}^2)$$

$$V = 96 \text{ in.} \times \pi(144 \text{ in.}^2)$$

$$V = 43{,}407 \text{ ft}^3$$

## Volume of a Cone and Sphere

### Volume of a Cone

$$\text{Volume of cone} = \frac{\pi}{12} \times \text{diameter} \times \text{diameter} \times \text{height}$$

$$\frac{\pi}{12} = \frac{3.14}{12} = 0.262 \tag{11.7}$$

✔ **Key Point:** The diameter used in the formula is the diameter of the base of the cone.

**Example 11.12**

*Problem*

The bottom section of a circular settling tank has the shape of a cone. How many cubic feet of water are contained in this section of the tank if the tank has a diameter of 120 ft and the cone portion of the unit has a depth of 6 ft?

*Solution*

$$\text{Volume (ft}^3) = 0.262 \times 120 \text{ ft} \times 120 \text{ ft} \times 6 \text{ ft} = 22{,}637 \text{ ft}^3$$

### Volume of a Sphere

$$\text{Volume} = \frac{3.14}{6} \times \text{diameter} \times \text{diameter} \times \text{diameter}$$

$$\frac{\pi}{6} = \frac{3.14}{6} = 0.524 \tag{11.8}$$

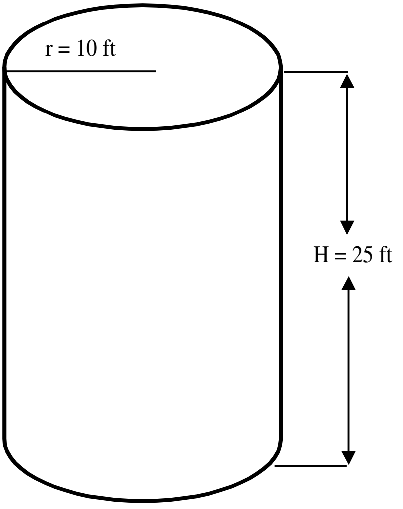


**FIGURE 11.8** Circular or cylindrical water tank.

## Example 11.13

*Problem*

What is the volume (in cubic feet) of a gas storage container that is spherical and has a diameter of 60 ft?

*Solution*

$$\text{Volume (ft}^3\text{)} = 0.524 \times 60 \text{ ft} \times 60 \text{ ft} \times 60 \text{ ft} = 113{,}184 \text{ ft}^3$$

## Volume of a Circular or Cylindrical Tank

Circular process and various water/chemical storage tanks are commonly found in water/wastewater treatment. A circular tank consists of a circular floor surface with a cylinder rising above it (see Figure 11.8). The volume of a circular tank is calculated by multiplying the surface area times the height of the tank walls.

## Example 11.14

*Problem*

A tank is 20 feet in diameter and 25 feet deep. How many gallons of water will it hold?

> ✔ **Hint:** In this type of problem, calculate the surface area first, multiply by the height, and then convert to gallons.

*Solution*

$$r = D \div 2 = 20 \text{ ft} \div 2 = 10 \text{ ft}$$

$$A = \pi \times r^2 = \pi \times 10 \text{ ft} \times 10 \text{ ft}$$

$$\text{A} = 314 \text{ ft}^2$$

$$V = A \times H$$

$$V = 314\ \text{ft}^2 \times 25\ \text{ft} = 7850\ \text{ft}^3$$

$$V = 7850\ \text{ft}^3 \times 7.5\ \text{gal/ft}^3 = 58{,}875\ \text{gal}$$

# 12 Force, Pressure, and Head Calculations

## TOPICS



Before we study calculations involving force, pressure, and head, we must first define some terms:

- *Force* — Push exerted by water on any confined surface; force can be expressed in pounds, tons, grams, or kilograms.
- *Pressure* — Force per unit area; the most common way of expressing pressure is in pounds per square inch (psi).
- *Head* — Vertical distance or height of water above a reference point; head is usually expressed in feet. In the case of water, head and pressure are related.

## FORCE AND PRESSURE

Figure 12.1 helps to illustrate these terms. A cubical container measuring 1 foot on each side can hold 1 cubic foot of water. It is a basic fact of science that 1 cubic foot of water weighs 62.4 pounds and contains 7.48 gallons. The force acting on the bottom of the container would be 62.4 pounds per square foot. The area of the bottom in square inches is:

$$1\ \text{ft}^2 = 12\ \text{in.} \times 12\ \text{in.} = 144\ \text{in}^2$$

Therefore, the pressure in pounds per square inch (psi) is:

$$\frac{62.4\ \text{lb/ft}^2}{1\ \text{ft}^2} = \frac{62.4\ \text{lb/ft}^2}{144\ \text{in.}^2/\text{ft}^2} = 0.433\ \text{lb/in.}^2\ (\text{psi})$$

If we use the bottom of the container as our reference point, the head would be 1 foot. From this, we can see that 1 foot of head is equal to 0.433 psi — an important parameter to remember. Figure 12.2 illustrates some other important relationships between pressure and head.

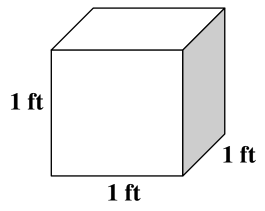


**FIGURE 12.1** One cubic foot of water weights 62.4 lbs.

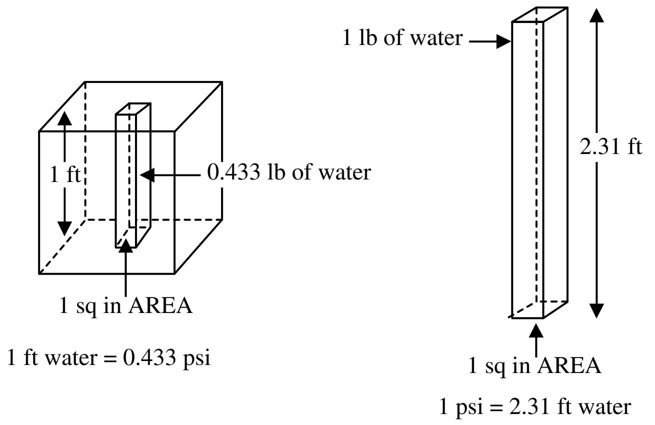


**FIGURE 12.2** Shows the relationship between pressure and head.

> **Important Point:** Force acts in a particular direction; water in a tank exerts force down on the bottom and out of the sides. Pressure, however, acts in all directions. A marble at a water depth of 1 foot would experience 0.433 psi of pressure acting inward on all sides.

Using the preceding information, we can develop Equation 12.1 and Equation 12.2 for calculating pressure and head:

$$\text{Pressure (psi)} = 0.433 \times \text{head (ft)} \tag{12.1}$$

$$\text{Head (ft)} = 2.31 \times \text{pressure (psi)} \tag{12.2}$$

## HEAD

As mentioned, head is the vertical distance the water must be lifted from the supply tank or unit process to the discharge. The total head includes the vertical distance the liquid must be lifted (static head), the loss to friction (friction head), and the energy required to maintain the desired velocity (velocity head).

$$\text{Total head} = \text{static head} + \text{friction head} + \text{velocity head} \tag{12.3}$$

### STATIC HEAD

*Static head* is the actual vertical distance the liquid must be lifted:

$$\text{Static head} = \text{discharge elevation} - \text{supply elevation} \tag{12.4}$$

### Example 12.1

*Problem*

A supply tank is located at an elevation of 108 ft. The discharge point is at an elevation of 205 ft. What is the static head in feet?

*Solution*

$$\text{Static head (ft)} = 205 \text{ ft} - 108 \text{ ft} = 97 \text{ ft}$$

## Friction Head

*Friction head* is the equivalent distance of the energy that must be supplied to overcome friction. Engineering references include tables showing the equivalent vertical distance for various sizes and types of pipes, fittings, and valves. The total friction head is the sum of the equivalent vertical distances for each component:

$$\text{Friction head (ft)} = \text{energy losses due to friction} \tag{12.5}$$

## Velocity Head

*Velocity head* is the equivalent distance of the energy consumed in achieving and maintaining the desired velocity in the system:

$$\text{Velocity head (ft)} = \text{energy losses to maintain velocity} \tag{12.6}$$

## Total Dynamic Head (Total System Head)

$$\text{Total head} = \text{static head} + \text{friction head} + \text{velocity head} \tag{12.7}$$

## Pressure/Head

The pressure exerted by water/wastewater is directly proportional to its depth or head in the pipe, tank, or channel. If the pressure is known, the equivalent head can be calculated.

$$\text{Head (ft)} = \text{pressure (psi)} \times 2.31 \text{ ft/psi} \tag{12.8}$$

### Example 12.2

*Problem*

The pressure gauge on the discharge line form the influent pump reads 75.3 psi. What is the equivalent head in feet?

*Solution*

$$\text{Head (ft)} = 75.3 \times 2.31 \text{ ft/psi} = 173.9 \text{ ft}$$

## Head/Pressure

If the head is known, the equivalent pressure can be calculated by:

$$\text{Pressure (psi)} = \frac{\text{head (ft)}}{2.31 \text{ ft/psi}} \tag{12.9}$$

**Example 12.3**

*Problem*

A tank is 15 feet deep. What is the pressure (in pounds per square inch) at the bottom of the tank when it is filled with wastewater?

*Solution*

$$\text{Pressure (psi)} = \frac{15 \text{ ft}}{2.31 \text{ ft/psi}}$$

$$= 6.49 \text{ psi}$$

Before we look at a few example problems dealing with force, pressure, and head, it is important to list the key points related to force, pressure, and head:

- By definition, water weighs 62.4 pounds per cubic foot.
- The surface of any one side of a cube contains 144 square inches (12 in. × 12 in. = 144 in.$^2$); therefore, the cube contains 144 columns of water that are 1 foot tall and 1 inch square.
- The weight of each of these pieces can be determined by dividing the weight of the water in the cube by the number of square inches:

$$\text{Weight} = \frac{62.4 \text{ lb}}{144 \text{ in.}^2} = 0.433 \text{ lb/in.}^2 \text{ or } 0.433 \text{ psi}$$

- Because this is the weight of one column of water 1 foot tall, the true expression would be 0.433 psi per foot of head, or 0.433 psi/ft.

✔ **Key Point:** 1 foot of head = 0.433 psi.

In addition to remembering the important parameter of 1 foot of head = 0.433 psi, it is important to understand the relationship between pressure and feet of head — in other words, how many feet of head 1 psi represents. This is determined by dividing 1 by 0.433:

$$\text{Feet of head} = \frac{1 \text{ ft}}{0.433 \text{ psi}} = 2.31 \text{ ft/psi}$$

If a pressure gauge read 12 psi, the height of the water that would represent this pressure would be 12 psi × 2.31 ft/psi = 27.7 feet.

✔ **Key Point:** Both the above conversions are commonly used in water/wastewater treatment calculations; however, the most accurate conversion is 1 ft = 0.433 psi. This is the conversion we use throughout this text.

## FORCE, PRESSURE, AND HEAD EXAMPLE PROBLEMS

**Example 12.4**

*Problem*

Convert 40 psi to feet head.

*Solution*

$$\frac{\text{psi}}{1} \times \frac{\text{ft}}{0.433\text{ psi}} = 92.4\text{ ft}$$

**Example 12.5**

*Problem*

Convert 40 feet to psi.

*Solution*

$$40\,\frac{\text{ft}}{1} \times \frac{0.433\text{ psi}}{1\text{ ft}} = 17.32\text{ psi}$$

As the above examples demonstrate, when converting psi to feet, we divide by 0.433; to convert feet to psi, we multiply by 0.433. The above process can be most helpful in clearing up any confusion about whether to multiply or divide. We have another way, however — one that may be more beneficial and easier for many operators to use. Notice that the relationship between psi and feet is almost two to one. It takes slightly more than 2 feet to make one psi; therefore, when looking at a problem where the data are in pressure, the result should be in feet, and the answer should be at least twice as large as the starting number. For instance, if the pressure is 25 psi, we intuitively know that the head is over 50 feet; therefore, we must divide by 0.433 to obtain the correct answer.

**Example 12.6**

*Problem*

Convert a pressure of 45 pounds per square inch to feet of head.

*Solution*

$$45\,\frac{\text{psi}}{1} \times \frac{1\text{ ft}}{0.433\text{ psi}} = 104\text{ ft}$$

**Example 12.7**

*Problem*

Convert 15 psi to feet.

*Solution*

$$15\,\frac{\text{psi}}{1} \times \frac{1\text{ ft}}{0.433\text{ psi}} = 34.6\text{ ft}$$

**Example 12.8**

*Problem*

Between the top of a reservoir and the watering point, the elevation is 125 feet. What will the static pressure be at the watering point?

*Solution*

$$125\,\frac{\text{psi}}{1} \times \frac{1\text{ ft}}{0.433\text{ psi}} = 54.1\text{ ft}$$

### Example 12.9

*Problem*

Find the pressure (in psi) in a tank 12 feet deep at a point 5 feet below the water surface.

*Solution*

$$\text{Pressure (psi)} = 0.433 \times 5 \text{ ft}$$

$$= 2.17 \text{ psi}$$

### Example 12.10

*Problem*

A pressure gauge at the bottom of a tank reads 12.2 psi. How deep is the water in the tank?

*Solution*

$$\text{Head (ft)} = 2.31 \times 12.2 \text{ psi}$$

$$= 28.2 \text{ ft}$$

### Example 12.11

*Problem*

What is the pressure (static pressure) 4 miles beneath the ocean surface?

*Solution*

Change miles to ft, then to psi.

$$5280 \text{ ft/mile} \times 4 = 21{,}120 \text{ ft}$$

$$\frac{21{,}120 \text{ ft}}{2.31 \text{ ft/psi}} = 9143 \text{ psi}$$

### Example 12.12

*Problem*

A 150-ft-diameter cylindrical tank contains 2.0 MG water. What is the water depth? At what pressure would a gauge at the bottom read in psi?

*Solution*

- Step 1: Change MG to cu ft:

$$\frac{2{,}000{,}000 \text{ gal}}{7.48} = 267{,}380 \text{ cu ft}$$

- Step 2: Using volume, solve for depth:

$$\text{Volume } (V) = .785 \times D^2 \times \text{depth}$$

$$V = 267{,}380 \text{ cu ft} = .785 \times (150)^2 \times \text{depth}$$

$$\text{Depth} = 15.1 \text{ ft}$$

### Example 12.13

*Problem*

The pressure in a pipe is 70 psi. What is the pressure in feet of water? What is the pressure in psf?

*Solution*

- Step 1: Convert pressure to feet of water:

$$70 \text{ psi} \times 2.31 \text{ ft/psi} = 161.7 \text{ ft of water}$$

- Step 2: Convert psi to psf:

$$70 \text{ psi} \times 144 \text{ sq in./sq ft} = 10{,}080 \text{ psf}$$

### Example 12.14

*Problem*

The pressure in a pipeline is 6476 psf. What is the head on the pipe?

*Solution*

$$\text{Head on pipe} = \text{ft of pressure}$$

$$\text{Pressure} = \text{weight} \times \text{height}$$

$$6476 \text{ psf} = 62.4 \text{ lb/cu ft} \times \text{height}$$

$$\text{Height} = 104 \text{ ft}$$

# 13 Mass Balance and Measuring Plant Performance

## TOPICS



The simplest way to express the fundamental engineering principle of *mass balance* is to say, "Everything has to go somewhere." More precisely, the *law of conservation of mass* says that when chemical reactions take place, matter is neither created nor destroyed. This important concept allows us to track materials (that is, pollutants, microorganisms, chemicals, and other materials) from one place to another. The concept of mass balance plays an important role in treatment plant operations (especially wastewater treatment), where we assume a balance exists between the material entering and leaving the treatment plant or a treatment process: "What comes in must equal what goes out." This concept is very helpful in evaluating biological systems, sampling and testing procedures, and many other unit processes within the treatment system. In the following sections, we illustrate how the mass balance concept is used to determine the quantity of solids entering and leaving settling tanks and mass balance using biological oxygen demand (BOD) removal.

## MASS BALANCE FOR SETTLING TANKS

The mass balance for the settling tank calculates the quantity of solids entering and leaving the unit.

> **Key Point:** The two numbers — in (influent) and out (effluent) — must be within 10 to 15% of each other to be considered acceptable. Larger discrepancies may indicate sampling errors or increasing solids levels in the unit or undetected solids discharge in the tank effluent.

To get a better feel for how the mass balance for settling tanks procedure is formatted for actual use, consider Figure 13.1 and the accompanying steps provided below. We will use an example computation to demonstrate how mass balance is actually used in wastewater operations:

- Step 1: Solids in = pounds of influent suspended solids
- Step 2: Pounds of effluent suspended solids
- Step 3: Biosolids solids out = pounds of biosolids solids pumped per day
- Step 4: Solids in — (solids out + biosolids solids pumped)

### Example 13.1

*Problem*

A settling tank receives a daily flow of 4.20 MGD. The influent contains 252 mg/L suspended solids, and the unit effluent contains 140 mg/L suspended solids. The biosolids pump operates 10

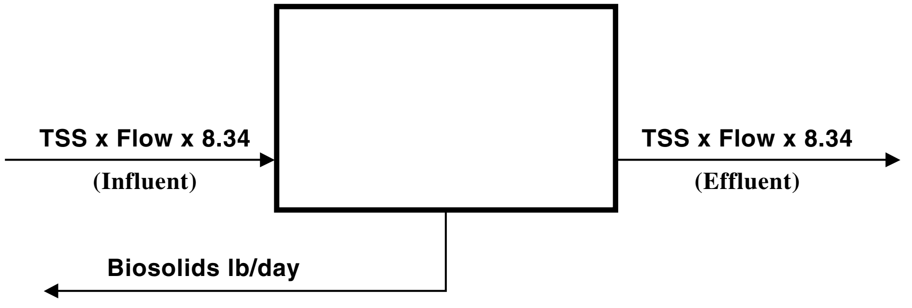


**FIGURE 13.1** Mass balance for settling tanks.

min/h and removes biosolids at the rate of 40 gpm. The biosolids content is 4.2% solids. Determine if the mass balance for solids removal is within the acceptable 10 to 15% range.

*Solution*

- Step 1: Solids in = 252 mg/L × 4.20 MGD × 8.34 = 8827 lb/d
- Step 2: Solids out = 140 mg/L × 4.20 MGD × 8.34 = 4904 lb/d
- Step 3: Biosolids solids = 10 min/hr × 24 hr/day × 40 gpm × 8.34 × 0.042 = 3363 lb/d
- Step 4: Balance = 8827 lb/day – (4904 lb/day + 3363 lb/day) = 560 lb, or 6.3%

## MASS BALANCE USING BOD REMOVAL

The amount of BOD removed by a treatment process is directly related to the quantity of solids the process will generate. Because the actual amount of solids generated will vary with operational conditions and design, exact figures must be determined on a case-by-case basis; however, research has produced general conversion rates for many of the common treatment processes. These values are given in Table 13.1 and can be used if plant-specific information is unavailable. Using these factors, the mass balance procedure determines the amount of solids the process is anticipated to produce. This quantity is compared with actual biosolids production to determine the accuracy of the sampling and/or the potential for solids buildup in the system or unrecorded solids discharges (see Figure 13.2).

**TABLE 13.1**
**General Conversion Rates**

| Process Type | Conversion Factor (lb Solids/lb BOD Removal) |
|---|---|
| Primary treatment | 1.7 |
| Trickling filters | 1.0 |
| Rotating biological contactors | 1.0 |
| Activated biosolids with primary | 0.7 |
| Activated biosolids without primary | |
| Conventional | 0.85 |
| Extended air | 0.65 |
| Contact stabilization | 1.0 |
| Step feed | 0.85 |
| Oxidation ditch | 0.65 |

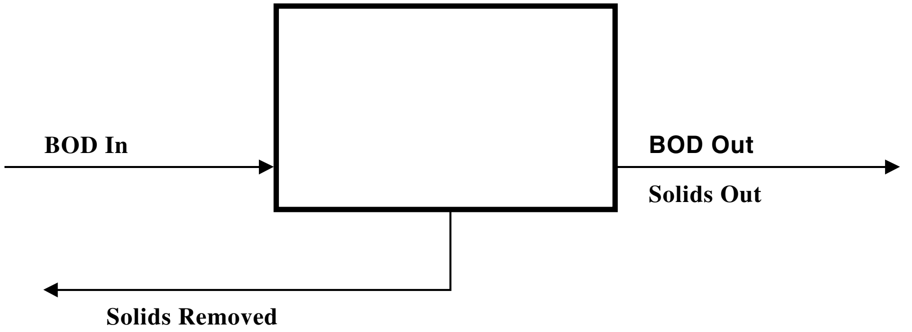


**FIGURE 13.2** Comparison of BOD in and BOD out.

- Step 1: $BOD_{in}$ = influent BOD × flow × 8.34
- Step 2: $BOD_{out}$ = effluent BOD × flow × 8.34
- Step 3: BOD pounds removed = $BOD_{in} - BOD_{out}$
- Step 4: Solids generated (lb) = BOD removed (lb × factor)
- Step 5: Solids removed = sludge pumped (gpd) × % solids × 8.34
- Step 6: Effluent solids (mg/L) × flow (MGD) × 8.34

## Example 13.2

### *Problem*

A conventional activated biosolids system with primary treatment is operating at the levels listed below. Does the mass balance for the activated biosolids system indicate a problem?

| | |
|---|---|
| Plant influent BOD | 250 mg/L |
| Primary effluent BOD | 166 mg/L |
| Activated biosolids system effluent BOD | 25 mg/L |
| Activated biosolids system effluent total suspended solids (TSS) | 19 mg/L |
| Plant flow | 11.40 MGD |
| Waste concentration | 6795 mg/L |
| Waste flow | 0.15 MGD |

### *Solution*

- $BOD_{in}$ = 166 mg/L × 11.40 MGD × 8.34 = 15,783 lb/day
- $BOD_{out}$ = 25 mg/L × 11.40 MGD × 8.34 = 2377 lb/day
- BOD removed = 15,783 lb/d – 2377 lb/d = 13,406 lb/day
- Solids produced = 13,406 lb/day × 0.7 lb solids/lb BOD = 9384 lb solids/day
- Solids removed = 6795 mg/L × 0.15 MGD × 8.34 = 8501 lb/day
- Difference = 9384 lb/day – 8501 lb/day = 883 lb/day, or 9.4%

These results are within the acceptable range.

**Key Point:** We have demonstrated two ways in which mass balance can be used; however, it is important to note that the mass balance concept can be used for all aspects of wastewater and solids treatment. In each case, the calculations must take into account all of the sources of material entering the process and all of the methods available for removal of solids.

## MEASURING PLANT PERFORMANCE

To evaluate how well a plant or unit process is performing, performance efficiency or percent (%) removal is used. The results obtained can be compared with those listed in a plant's operation and maintenance (O&M) manual to determine if the facility is performing as expected. This section presents sample calculations often used to measure plant performance/efficiency.

The *efficiency* of a unit process is its effectiveness in removing various constituents from the wastewater or water. Suspended solids and BOD removal are therefore the most common calculations of unit process efficiency. In wastewater treatment, the efficiency of a sedimentation basin may be affected by such factors as the types of solids in the wastewater, the temperature of the wastewater, and the age of the solids. Typical removal efficiencies for a primary sedimentation basin are as follows:

- Settleable solids 90 to 99%
- Suspended solids 40 to 60%
- Total solids 10 to 15%
- BOD 20 to 50%

### Plant Performance/Efficiency

✓ Key Point: The calculation used for determining the performance (percent removal) for a digester is different from that used for performance (percent removal) for other processes. Care must be taken to select the right formula:

$$\%\ \text{Removal} = \frac{[\text{influent concentration} - \text{effluent concentration}] \times 100}{\text{influent concentration}} \tag{13.1}$$

**Example 13.3**

*Problem*

As shown in Figure 13.3, the influent $BOD_5$ is 247 mg/L, and the plant effluent BOD is 17 mg/L. What is the percent removal?

*Solution*

$$\%\ \text{Removal} = \frac{(247\ \text{mg/L} - 17\ \text{mg/L}) \times 100}{247\ \text{mg/L}} = 93\%$$

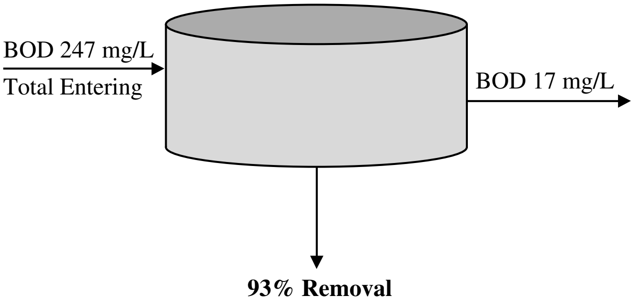


**FIGURE 13.3** Refers to Example 13.3.

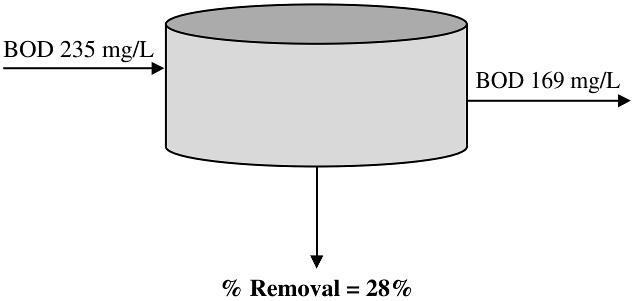


**FIGURE 13.4** Refers to Example 13.4.

## Unit Process Performance/Efficiency

Equation 13.1 is used again to determine unit process efficiency. The concentration entering the unit and the concentration leaving the unit (e.g., primary, secondary) are used to determine the unit performance:

$$\text{\% Removal} = \frac{[\text{influent concentration} - \text{effluent concentration}] \times 100}{\text{influent concentration}} \tag{13.1}$$

### Example 13.4

*Problem*

As shown in Figure 13.4, the primary influent BOD is 235 mg/L, and the primary effluent BOD is 169 mg/L. What is the percent removal?

*Solution*

$$\text{\% Removal} = \frac{(235\ \text{mg/L} - 169\ \text{mg/L}) \times 100}{235\ \text{mg/L}} = 28\%$$

## Percent Volatile Matter Reduction in Sludge

The calculation used to determine *percent volatile matter* (%VM) reduction is more complicated because of the changes occurring during biosolids digestion.

$$\text{\% VM reduction} = \frac{(\text{\% VM}_{in} - \text{\% VM}_{out}) \times 100}{[\text{\% VM}_{in} - (\text{\% VM}_{in} \times \text{\% VM}_{out})]}$$

### Example 13.5

*Problem:*

Using the digester data provided below, determine the percent volatile matter reduction.

Raw biosolids volatile matter = 74%
Digested biosolids volatile matter = 54%

*Solution*

$$\% \text{ VM reduction} = \frac{(0.74 - 0.54) \times 100}{\left[0.74 - (0.74 \times 0.54)\right]} = 59\%$$

See Figure 13.5.

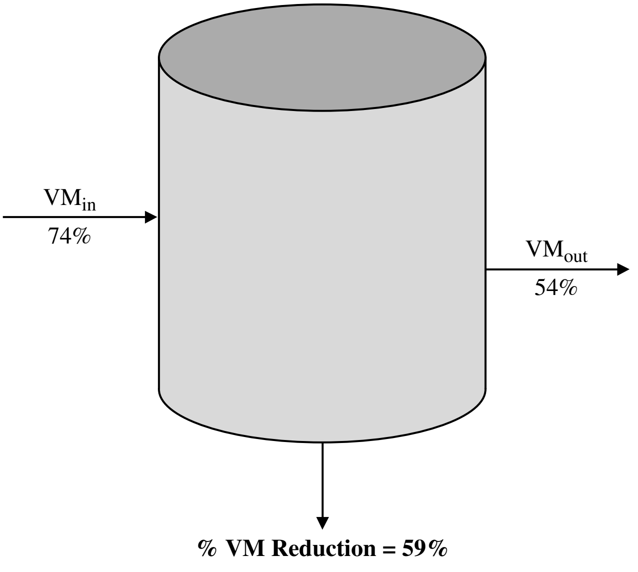


**FIGURE 13.5** Refers to Example 13.5.

# Part II

## Applied Math Concepts: Water Treatment

# 14 Pumping Calculations

## TOPICS



## PUMPING

Pumping facilities and appurtenances are required wherever gravity cannot be used to supply water to the distribution system under sufficient pressure to meet all service demands. Pumps are used to lift or elevate wastewater from a lower elevation to an adequate height at which it can flow by gravity or overcome hydrostatic head. A wastewater treatment facility has many pumping applications, including pumping of (1) raw or treated wastewater, (2) grit, (3) grease and floating solids, (4) dilute or well-thickened raw biosolids or digested biosolids (biosolids or supernatant return), and (5) dispensing of chemical solutions. Pumps and lift stations are used extensively in the collection system. Each of the various pumping applications is unique and requires specific design and pump selection considerations.

With few exceptions, the pumps used in water and wastewater treatment are the same. Because the pump is so perfectly suited to the tasks it performs and because the principles that make the pump work are physically fundamental, the idea that any new device would ever replace the pump is difficult to imagine. The pump is the workhorse of water/wastewater operations. Simply, pumps use energy to keep water and wastewater moving. To operate a pump efficiently, the operator and/or maintenance operator must be familiar with several basic principles of hydraulics. In addition, to operate various unit processes in both water and wastewater operations at optimum levels operators should know how to perform basic pumping calculations.

## BASIC WATER HYDRAULICS CALCULATIONS

### Weight of Water

Because water must be stored and/or kept moving in water supplies and wastewater must be collected, processed, and discharged to its receiving body, we must consider some basic relationships regarding the weight of water. One cubic foot of water weighs 62.4 pounds and contains 7.48 gallons. One

cubic inch of water weighs 0.0362 pounds. Water 1 foot deep will exert a pressure of 0.43 pounds per square inch (psi) on the bottom area (12 inches × 0.062 pounds per cubic inch [lb/in.$^3$]). A column of water 2 feet high exerts 0.86 psi, one that is 10 feet high exerts 4.3 psi, and one that is 52 feet high exerts:

$$52 \text{ ft} \times 0.43 \text{ psi/ft} = 22.36 \text{ psi}$$

A column of water 2.31 feet high will exert 1.0 psi. To produce a pressure of 40 psi requires a water column of:

$$40 \text{ psi} \times 2.31 \text{ ft/psi} = 92.4 \text{ ft}$$

The term *head* is used to designate water pressure in terms of the height of a column of water in feet. For example, a 10-foot column of water exerts 4.3 psi. This can be referred to as 4.3-psi pressure or 10 feet of head. If the static pressure in a pipe leading from an elevated water storage tank is 37 pounds per square inch (psi), what is the elevation of the water above the pressure gauge? Remembering that 1 psi = 2.31 and that the pressure at the gauge is 37 psi,

$$37 \text{ psi} \times 2.31 \text{ ft/psi} = 85.5 \text{ ft (rounded)}$$

## Weight of Water Related to the Weight of Air

The theoretical atmospheric pressure at sea level (14.7 psi) will support a column of water 34 feet high:

$$14.7 \text{ psi} \times 2.31 \text{ ft/psi} = 33.957 \text{ ft, or } 34 \text{ ft}$$

At an elevation of 1 mile above sea level, where the atmospheric pressure is 12 psi, the column of water would be only 28 feet high:

$$12 \text{ psi} \times 2.31 \text{ ft/psi} = 27.72 \text{ ft, or } 28 \text{ ft}$$

If a tube is placed in a body of water at sea level (e.g., a glass, a bucket, a water storage reservoir, lake, pool), water will rise in the tube to the same height as the water outside the tube. The atmospheric pressure of 14.7 psi will push down equally on the water surface inside and outside the tube. However, if the top of the tube is tightly capped and all of the air is removed from the sealed tube above the water surface, forming a *perfect vacuum*, the pressure on the water surface inside the tube will be 0 psi. The atmospheric pressure of 14.7 psi on the outside of the tube will push the water up into the tube until the weight of the water exerts the same 14.7 psi pressure at a point in the tube even with the water surface outside the tube. The water will rise 14.7 psi × 2.31 ft/psi = 34 feet. In practice, it is impossible to create a perfect vacuum, so the water will rise somewhat less than 34 feet; the distance it rises depends on the amount of vacuum created.

### Example 14.1

*Problem*

If enough air is removed from a tube to produce an air pressure of 9.7 psi above the water in the tube, how far will the water rise in the tube?

*Solution*

To maintain the 14.7 psi at the outside water surface level, the water in the tube must produce a pressure of 14.7 psi – 9.7 = 5.0 psi. The height of the column of water that will produce 5.0 psi is:

$$5.0 \text{ psi} \times 2.31 \text{ ft/psi} = 11.5 \text{ ft}$$

**Water at Rest**

*Stevin's law* states: "The pressure at any point in a fluid at rest depends on the distance measured vertically to the free surface and the density of the fluid." Stated as a formula, this becomes:

$$p = w \times h \tag{14.1}$$

where:

$p$ = Pressure in pounds per square foot (psf)
$w$ = Density in pounds per cubic foot (lb/ft$^3$)
$h$ = Vertical distance in feet

### Example 14.2

*Problem*

What is the pressure at a point 15 feet below the surface of a reservoir?

*Solution*

To calculate this, we must know that the density of water ($w$) is 62.4 pounds per cubic foot. Thus,

$$\begin{aligned} p &= w \times h \\ &= 62.4 \text{ lb/ft}^3 \times 15 \text{ ft} \\ &= 936 \text{ lb/ft}^2 \text{ (psf)} \end{aligned}$$

Waterworks/wastewater operators generally measure pressure in pounds per square *inch* rather than pounds per square *foot*. To convert, divide by 144 in.$^2$/ft$^2$ (12 in. × 12 in. = 144 in.$^2$):

$$p = \frac{936 \text{ lb/ft}^2}{144 \text{ in.}^2/\text{ft}^2} = 6.5 \text{ lb/in.}^2 \text{ (psi)}$$

## Gauge Pressure

We have defined *head* as the height that a column of water will rise due to the pressure at its base. We demonstrated that a perfect vacuum plus atmospheric pressure of 14.7 psi would lift the water 34 feet. If we now open the top of the sealed tube to the atmosphere and enclose the reservoir, then increase the pressure in the reservoir, the water will again rise in the tube. Because atmospheric pressure is essentially universal, we usually ignore the first 14.7-psi of actual pressure measurements and measure only the difference between the water pressure and the atmospheric pressure; we call this *gauge pressure*.

### Example 14.3

*Problem*

Water in an open reservoir is subjected to 14.7 psi of atmospheric pressure, but subtracting this 14.7 psi leaves a gauge pressure of 0 psi. This shows that the water would rise 0 feet above the reservoir surface. If the gauge pressure in a water main is 100 psi, how far will the water rise in a tube connected to the main?

*Solution*

$$100 \text{ psi} \times 2.31 \text{ ft/psi} = 231 \text{ ft}$$

## Water in Motion

The study of water in motion is much more complicated than that of water at rest. It is important to have an understanding of these principles because the water/wastewater in a treatment plant and/or distribution/collection system is nearly always in motion (much of this motion is the result of pumping, of course).

### Discharge

*Discharge* is the quantity of water passing a given point in a pipe or channel during a given period of time. It can be calculated by the formula:

$$Q = V \times A \tag{14.2}$$

where

$Q$ = Discharge in cubic feet per second (cfs)
$V$ = Water velocity in feet per second (fps or ft/sec)
$A$ = Cross-section area of the pipe or channel in square feet (ft$^2$)

Discharge can be converted from cfs to other units such as gallons per minute (gpm) or million gallons per day (MGD) by using appropriate conversion factors.

### Example 14.4

*Problem*

A pipe 12 inches in diameter has water flowing through it at 10 feet per second. What is the discharge in (1) cfs, (2) gpm, and (c) MGD?

*Solution*

Before we can use the basic formula, we must determine the area ($A$) of the pipe. The formula for the area is:

$$A = \pi \times \frac{D^2}{4} = \pi \times r^2$$

where

$\pi$ = Constant value 3.14159
$D$ = Diameter of the circle in feet
$r$ = Radius of the circle in feet

So the area of the pipe is:

$$A = \pi \times \frac{D^2}{4} = 3.14159 = 0.785 \text{ ft}^2$$

Now we can determine the discharge in cfs:

$$Q = V \times A = 10 \text{ ft/sec} \times 0.785 \text{ ft}^2 = 7.85 \text{ ft}^3\text{/sec or cfs}$$

To determine the discharge in gpm, we need to know that 1 cubic foot per second is equal to 449 gallons per minute, so:

$$7.85 \text{ cfs} \times 449 \text{ gpm/cfs} = 3520 \text{ gpm}$$

To determine the discharge in MGD, 1 million gallons per day is equal to 1.55 cfs, so:

$$\frac{7.85 \text{ cfs}}{1.55 \text{ cfs/MGD}} = 5.06 \text{ MGD}$$

### The Law of Continuity

*The law of continuity* states that the discharge at each point in a pipe or channel is the same as the discharge at any other point (provided water does not leave or enter the pipe or channel). In equation form, this becomes:

$$Q_1 = Q_2 \text{ or } A_1V_1 = A_2V_2 \tag{14.3}$$

### Example 14.5

#### *Problem*

A pipe 12 inches in diameter is connected to a 6-inch-diameter pipe. The velocity of the water in the 12-inch pipe is 3 fps. What is the velocity in the 6-in. pipe?

#### *Solution*

Using the equation:

$$A_1V_1 = A_2V_2$$

we need to determine the area of each pipe:

- 12-inch pipe

$$A = \pi \times \frac{D^2}{4}$$

$$= 3.1419 \times \frac{(1 \text{ ft})^2}{4}$$

$$= 0.785 \text{ ft}^2$$

- 6-inch pipe

$$A = 3.14159 \times \frac{(0.5)^2}{4}$$

$$= 0.196 \text{ ft}^2$$

The continuity equation now becomes:

$$(0.785 \text{ ft}^2) \times (3 \text{ ft/sec}) = (0.196 \text{ ft}^2) \times V_2$$

Solving for $V_2$,

$$V_2 = \frac{\left(0.785 \text{ ft}^2\right) \times \left(3 \text{ ft/s}\right)}{0.196 \text{ ft}^2}$$

$$= 12 \text{ ft/sec or fps}$$

### Pipe Friction

The flow of water in pipes is caused by the pressure applied behind it either by gravity or by hydraulic machines (pumps). The flow is retarded by the friction of the water against the inside of the pipe. The resistance of flow offered by this friction depends on the size (diameter) of the pipe, the roughness of the pipe wall, and the number and type of fittings (bends, valves, etc.) along the pipe. It also depends on the speed of the water through the pipe — the more water being pumped through a pipe, the greater the pressure required to overcome the friction. The resistance can be expressed in terms of the additional pressure required to push the water through the pipe, in either pounds per square inch or feet of head. Because it is a reduction in pressure, it is often referred to as *friction loss* or *head loss*.

Friction loss increases as:

- Flow rate increases
- Pipe diameter decreases
- Pipe interior becomes rougher
- Pipe length increases
- Pipe is constricted

The actual calculation of friction loss is beyond the scope of this text. Many published tables give the friction loss for various types and diameters of pipe and standard fittings. What is more important here is recognition of the loss of pressure or head due to the friction of water flowing through a pipe. One of the factors in friction loss is the roughness of the pipe wall. A number called the C factor indicates pipe wall roughness; the *higher* the C factor, the *smoother* the pipe.

> **Note:** C factor is derived from the letter C in the Hazen–Williams equation for calculating water flow through a pipe.

Some of the roughness in the pipe is due to the material; for example, cast iron pipe is rougher than plastic. Additionally, the roughness will increase with corrosion of the pipe material and deposits of sediment in the pipe. New water pipes should have a C factor of 100 or more; older pipes can have C factors very much lower than this. To determining C factor, we usually use the published tables. When the friction losses for fittings are factored in, other published tables are also available to make the proper determinations. It is standard practice to calculate the head loss from fittings by substituting the *equivalent length of pipe*, which is also available from published tables.

## BASIC PUMPING CALCULATIONS

Certain computations used for determining various pumping parameters are important to the water/wastewater operator. In this section, we use basic-pumping calculations relevant to the subject matter.

### Pumping Rates

> **Important Point:** The rate of flow produced by a pump is expressed as the volume of water pumped during a given period.

The mathematical problems most often encountered by water/wastewater operators when determining pumping rates are often determined by using Equation 14.4 and/or Equation 14.5:

$$\text{Pumping rate (gpm)} = \frac{\text{gallons}}{\text{minutes}} \tag{14.4}$$

$$\text{Pumping rate (gph)} = \frac{\text{gallons}}{\text{hours}} \tag{14.5}$$

### Example 14.6

*Problem*

The meter on the discharge side of the pump reads in hundreds of gallons. If the meter shows a reading of 110 at 2:00 p.m. and 320 at 2:30 p.m., what is the pumping rate expressed in gallons per minute?

*Solution*

The problem asks for pumping rate in gallons per minute (gpm), so we use Equation 14.4.

- Step 1: To solve this problem, we must first find the total gallons pumped (determined from the meter readings).

$$32{,}000 \text{ gal} - 11{,}000 \text{ gal} = 21{,}000 \text{ gal}$$

- Step 2: This quantity was pumped between 2:00 p.m. and 2:30 p.m. for a total of 30 minutes. From this information, calculate the gpm pumping rate:

$$\text{Pumping rate (gpm)} = \frac{21{,}000 \text{ gal}}{30 \text{ min}}$$

$$= 700 \text{ gpm pumping rate}$$

### Example 14.7

*Problem*

During a 15-minute pumping test, 16,400 gallons were pumped into an empty rectangular tank. What is the pumping rate in gallons per minute?

*Solution*

The problem asks for the pumping rate in gallons per minute, so again we use Equation 14.4.

$$\text{Pumping rate (gpm)} = \frac{16{,}400 \text{ gallons}}{15 \text{ minutes}}$$

$$= 1033 \text{ gpm pumping rate}$$

### Example 14.8

*Problem*

A tank 50 feet in diameter is filled with water to a depth of 4 feet. To conduct a pumping test, the outlet valve to the tank is closed and the pump is allowed to discharge into the tank. After 80 minutes, the water level is 5.5 feet. What is the pumping rate in gallons per minute?

*Solution*

- Step 1: We must first determine the volume pumped in cubic feet:

$$\text{Volume pumped} = (\text{area of circle})(\text{depth})$$
$$= (0.785)(50\text{ ft})(50\text{ ft})(1.5\text{ ft})$$
$$= 2944\text{ ft}^3\text{ (rounded)}$$

- Step 2: Convert the cubic-foot volume to gallons:

$$(2944\text{ ft}^3)(7.48\text{ gal/ft}^3) = 22{,}021\text{ gallons (rounded)}$$

- Step 3: The pumping test was conducted over a period of 80 minutes. Using Equation 14.4, calculate the pumping rate in gallons per minute:

$$\text{Pumping rate (gpm)} = \frac{22{,}021\text{ gallons}}{80\text{ minutes}}$$
$$= 275.3\text{ gpm (rounded)}$$

## Calculating Head Loss

✓ **Important Note:** Pump head measurements are used to determine the amount of energy a pump can or must impart to the water; they are measured in feet.

One of the principle calculations in pumping problems is used to determine *head loss*. The following formula is used to calculate head loss:

$$H_f = K(V^2/2g) \tag{14.6}$$

where

$H_f$ = friction head
$K$ = friction coefficient
$V$ = velocity in pipe
$g$ = gravity (32.17 ft/sec/sec)

### Calculating Head

For centrifugal pumps and positive displacement pumps, several other important formulae are used to determine *head*. In centrifugal pump calculations, conversion of discharge pressure to discharge head is the norm. Positive displacement pump calculations often result in pressures expressed in pounds per square inch. In the following formulae, $W$ expresses the specific weight of liquid in pounds per cubic foot. For water at 68°F, $W$ is 62.4 lb/ft$^3$. A water column 2.31 feet high exerts a pressure of 1 psi on 64°F water. Use the following formulae to convert discharge pressure in psig to head in feet:

- Centrifugal pumps

$$H\text{ (ft)} = \frac{P\text{ (psig)} \times 2.31}{\text{specific gravity}} \tag{14.7}$$

- Positive displacement pumps

$$H\ (\text{ft}) = \frac{P\ (\text{psig}) \times 144}{W} \tag{14.8}$$

To convert head into pressure:

- Centrifugal pumps

$$P\ (\text{psi}) = \frac{H\ (\text{ft}) \times \text{specific gravity}}{2.31} \tag{14.9}$$

- Positive displacement pumps

$$P\ (\text{psi}) = \frac{H\ (\text{ft}) \times W}{W} \tag{14.10}$$

### Calculating Horsepower and Efficiency

When pushing a certain amount of water at a given pressure, a pump performs the work. When considering the work being done, we measure the rate at which the work is being done. This is called *power* and is labeled as foot-pounds/second (ft-lb/sec). At some point in the past, it was determined that the ideal work animal, the horse, could move 550 pounds 1 foot, in 1 second. This unit became known as *horsepower*. One horsepower equals 33,000 ft-lb/min. The two basic terms for horsepower are:

- Hydraulic horsepower (whp)
- Brake horsepower (bhp)

#### Hydraulic Horsepower (whp)

One hydraulic horsepower equals the following:

- 550 ft-lb/sec
- 33,000 ft-lb/min
- 2545 British thermal units per hour (Btu/hr)
- 0.746 kW
- 1.014 metric hp

To calculate the hydraulic horsepower (whp) using flow in gpm and head in feet, use the following formula for centrifugal pumps:

$$\text{whp} = \frac{\text{flow}\ (\text{gpm}) \times \text{head}\ (\text{ft}) \times \text{specific gravity}}{3960} \tag{14.11}$$

When calculating horsepower for positive displacement pumps, common practice is to use pounds per square inch for pressure. Then, the hydraulic horsepower becomes:

$$\text{whp} = \frac{\text{flow}\ (\text{gpm}) \times \text{pressure}\ (\text{psi})}{3960} \tag{14.12}$$

### Pump Efficiency and Brake Horsepower (bhp)

When a motor–pump combination is used (for any purpose), neither the pump nor the motor will be 100% efficient. Not all of the power supplied by the motor to the pump (*brake horsepower*, or bhp) will be used to lift the water (*water* or *hydraulic horsepower*) — some of the power is used to overcome friction within the pump. Similarly, not all of the power of the electric current driving the motor (*motor horsepower*, or mhp) will be used to drive the pump — some of the current is used to overcome friction within the motor, and some current is lost in the conversion of electrical energy to mechanical power.

> ✔ **Note:** Depending on size and type, pumps are usually 50 to 85% efficient, and motors are usually 80 to 95% efficient. The efficiency of a particular motor or pump is given in the manufacturer's technical manual accompanying the unit.

The brake horsepower (bhp) of a pump is equal to hydraulic horsepower divided by efficiency. Thus, the bhp formula becomes:

$$\text{bhp} = \frac{\text{flow (gpm)} \times \text{head (ft)} \times \text{specific gravity}}{3960 \times \text{efficiency}} \tag{14.13}$$

or

$$\text{bhp} = \frac{\text{flow (gpm)} \times \text{pressure (psig)}}{1714 \times \text{efficiency}} \tag{14.14}$$

### Example 14.9

*Problem*

Calculate the bhp requirements for a pump handling saltwater and having a flow of 600 gpm with 40-psi differential pressure. The specific gravity of saltwater at 68°F is equal to 1.03. The pump efficiency is 85%.

*Solution*

To use Equation 14.13, convert the pressure differential to total differential head (TDH) = 40 × (2.31/1.03) = 90 ft.

$$\text{bhp} = \frac{600 \times 90 \times 1.03}{3960 \times 0.85}$$

$$= 16.5 \text{ hp (rounded)}$$

Using Equation 14.14:

$$\text{bhp} = \frac{600 \times 40}{1714 \times 0.85}$$

$$= 16.5 \text{ hp (rounded)}$$

> ✔ **Important Point:** Horsepower requirements vary with flow. Generally, if the flow is greater, the horsepower required to move the water is greater.

When the motor, brake and motor horsepower are known and the *efficiency* is unknown, a calculation to determine motor or pump efficiency must be done. Equation 14.15 is used to determine percent efficiency:

$$\text{Percent efficiency} = \frac{\text{hp output}}{\text{hp input}} \times 100 \tag{14.15}$$

From Equation 14.15, the specific equations to be used for motor, pump, and overall efficiency equations are:

$$\text{Percent motor efficiency} = \frac{\text{bhp}}{\text{mhp}} \times 100$$

$$\text{Percent pump efficiency} = \frac{\text{whp}}{\text{bhp}} \times 100$$

$$\text{Percent overall efficiency} = \frac{\text{whp}}{\text{mhp}} \times 100$$

### Example 14.10

*Problem*

A pump has a water horsepower requirement of 8.5 whp. If the motor supplies the pump with 12 hp, what is the efficiency of the pump?

*Solution*

$$\begin{aligned}\text{Percent pump efficiency} &= \frac{\text{whp output}}{\text{bhp supplied}} \times 100\\ &= \frac{8.5\text{ whp}}{12\text{ bhp}} \times 100\\ &= 0.71 \times 100\\ &= 71\%\ (\text{rounded})\end{aligned}$$

### Example 14.11

*Problem*

What is the efficiency if an electric power equivalent to 25 hp is supplied to the motor and 14 hp of work is accomplished by the pump?

*Solution*

Calculate the percent of overall efficiency:

$$\begin{aligned}\text{Percent overall efficiency} &= \frac{\text{hp output}}{\text{hp supplied}} \times 100\\ &= \frac{14\text{ whp}}{24\text{ mhp}} \times 100\\ &= 0.56 \times 100\\ &= 56\%\end{aligned}$$

#### Example 14.12

*Problem*

12 kW (kilowatts) of power is supplied to the motor. If the brake horsepower is 14 hp, what is the efficiency of the motor?

*Solution*

First, convert the kilowatts power to horsepower. Based on the fact that 1 hp = 0.746 kW, the equation becomes:

$$\frac{12 \text{ kW}}{0.746 \text{ kW/hp}} = 16.09 \text{ hp}$$

Now calculate the percent efficiency of the motor:

$$\begin{aligned}
\text{Percent efficiency} &= \frac{\text{hp output}}{\text{hp supplied}} \times 100 \\
&= \frac{14 \text{ bhp}}{16.09 \text{ mhp}} \times 100 \\
&= 87\%
\end{aligned}$$

### Specific Speed

*Specific speed* ($N_s$) refers to the speed of an impeller when pumping 1 gpm of liquid at a differential head of 1 ft. Use the following equation for specific speed, where $H$ is at the best efficiency point:

$$N_s = \frac{\text{rpm} \times Q^{0.5}}{H^{0.75}} \tag{14.19}$$

where

rpm = revolutions per minute
$Q$ = flow (in gpm)
$H$ = head (in ft)

Pump specific speeds vary between pumps. No absolute rule sets the specific speed for different kinds of centrifugal pumps; however, the following $N_s$ ranges are quite common:

- Volute, diffuser, and vertical turbine = 500 to 5000
- Mixed flow = 5000 to 10,000
- Propeller pumps = 9000 to 15,000

**Important Note:** The higher the specific speed of a pump, the higher its efficiency.

## POSITIVE DISPLACEMENT PUMPS

The clearest differentiation between centrifugal (or kinetic) pumps and positive-displacement pumps is based on the method by which pumping energy is transmitted to the liquid. Kinetic, or centrifugal

pumps, rely on a transformation of kinetic energy to static pressure. Positive-displacement pumps, on the other hand, discharge a given volume for each stroke or revolution (i.e., energy is added intermittently to the fluid flow). The two most common forms of positive-displacement pumps are *reciprocating-action pumps* (which use pistons, plungers, diaphragms, or bellows) and *rotary-action pumps* (which use vanes, screws, lobes, or progressing cavities). Regardless of form used, all positive-displacement pumps act to force liquid into a system regardless of the resistance that may oppose the transfer. The discharge pressure generated by a positive-displacement pump is, in theory, infinite.

The three basic types of positive displacement pumps discussed in this chapter are:

- Reciprocating pumps
- Rotary pumps
- Special-purpose pumps (peristaltic or tubing pumps)

## Volume of Biosolids Pumped (Capacity)

One of the most common positive displacement biosolids pumps is the piston pump. Each stroke of a piston pump displaces or pushes out biosolids. Normally, the piston pump is operated at about 50 gpm. To calculate capacity for positive displacement pump, we use the equation for the volume of biosolids pumped shown below:

$$\text{Volume of biosolids pumped}\left(\text{gal/min}\right)= \left[(0.785)\left(D^2\right)(\text{stroke length})\left(7.48\ \text{gal/ft}^3\right)(\text{strokes/min})\right] \tag{14.20}$$

### Example 14.13

*Problem*

A biosolids pump has a bore of 6 inches and a stroke length of 4 inches. If the pump operates at 50 strokes (or revolutions) per minute, how many gpm are pumped? (Assume 100% efficiency.)

*Solution*

$$\begin{aligned}\text{Volume of biosolids pumped} &= \text{gallons pumped/stroke} \times \text{no. of strokes/minute}\\ &= \left(0.785\times D^2 \times \text{stroke length}\times 7.48\ \text{gal/ft}\right)\times \text{strokes/min}\\ &= \left(0.785\times 0.5\ \text{ft}\times 0.5\ \text{ft}\times 0.33\ \text{ft}\times 7.48\ \text{gal/ft}^3\right)\times 50\ \text{strokes/min}\\ &= 0.48\ \text{gal/stroke}\times 50\ \text{strokes/min}\\ &= 24\ \text{gpm}\end{aligned}$$

### Example 14.14

*Problem*

A biosolids pump has a bore of 6 inches and a stroke setting of 3 inches. The pump operates at 50 revolutions per minute. If the pump operates a total of 60 minutes during a 24-hour period, what is the gallon-per-day pumping rate? (Assume the piston is 100% efficient.)

*Solution*

First calculate the gpm-pumping rate:

$$\begin{aligned}\text{Volume pumped (gpm)} &= \text{gallons pumped/stroke} \times \text{strokes/min} \\ &= \left(0.785 \times 0.5\ \text{ft} \times 0.5\ \text{ft} \times 0.25\ \text{ft} \times 7.48\ \text{gal/ft}^3\right) \times 50\ \text{strokes/min} \\ &= 0.37\ \text{gal/stroke} \times 50\ \text{strokes/min} \\ &= 18.5\ \text{gpm}\end{aligned}$$

Then convert gpm to a gpd pumping rate, based on total minutes pumped during the 24 hours:

$$18.5\ \text{gpm} \times 60/\text{day} = 1110\ \text{gpd}$$

# 15 Water Source and Storage Calculations

## TOPICS



## WATER SOURCES

Approximately 40 million cubic miles of water cover or reside within the Earth. The oceans contain about 97% of all water on Earth. The other 3% is freshwater: (1) snow and ice on the surface of earth account for about 2.25% of the water; (2) usable groundwater is approximately 0.3%, and (3) surface freshwater is less than 0.5%. In the U.S., average rainfall per year is approximately 2.6 feet (a volume of 5900 cubic kilometers, or $km^3$). Of this amount, approximately 71% evaporates (about 4200 cubic km), and 29% goes to stream flow (about 1700 cubic km).

Beneficial freshwater uses include manufacturing, food production, domestic and public needs, recreation, hydroelectric power production, and flood control. Stream flow withdrawn annually is about 7.5% (440 cubic km). Irrigation and industry use almost half of this amount (3.4%, or 200 cubic km per year). Municipalities use only about 0.6% (35 cubic km per year) of this amount. Historically, in the U.S., water usage has continued to increase (as might be expected). For example, in 1900, 40 billion gallons of freshwater were used. In 1975, the total increased to 455 billion gallons. Projected use in 2000 was about 720 billion gallons.

The primary sources of freshwater include the following:

- Captured and stored rainfall in cisterns and water jars
- Groundwater from springs, artesian wells, and drilled or dug wells
- Surface water from lakes, rivers, and streams
- Desalinized seawater or brackish groundwater
- Reclaimed wastewater

## WATER SOURCE CALCULATIONS

Water source calculations covered in this section apply to wells and pond and lake storage capacity. Specific well calculations discussed include well drawdown, well yield, specific yield, well-casing disinfection, and deep-well turbine pump capacity.

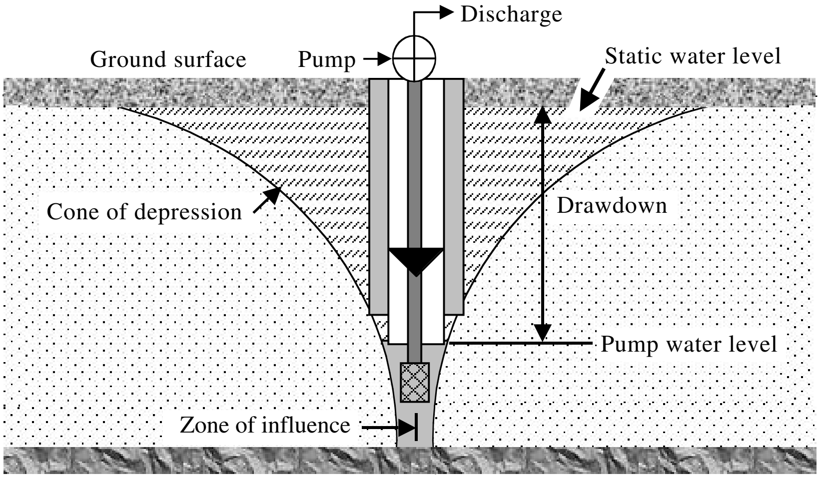


**FIGURE 15.1** Drawdown.

## Well Drawdown

*Drawdown* is the drop in the level of water in a well when water is being pumped (see Figure 15.1). Drawdown is usually measured in feet or meters. One of the most important reasons for measuring drawdown is to make sure that the source water is adequate and not being depleted. The data that are collected to calculate drawdown can indicate if the water supply is slowly declining. Early detection can give the system time to explore alternative sources, establish conservation measures, or obtain any special funding that may be needed to get a new water source. Well drawdown is the difference between the pumping water level and the static water level:

$$\text{Drawdown (ft)} = \text{pumping water level (ft)} - \text{static water level (ft)} \tag{15.1}$$

### Example 15.1

*Problem*

The static water level for a well is 70 ft. If the pumping water level is 90 ft, what is the drawdown?

*Solution*

Referring to Equation 15.1:

$$\text{Drawdown (ft)} = 90\text{ ft} - 70\text{ ft}$$

$$= 20\text{ ft}$$

### Example 15.2

*Problem*

The static water level of a well is 122 ft. The pumping water level is determined using the sounding line. The air pressure applied to the sounding line is 4.0 psi, and the length of the sounding line is 180 ft. What is the drawdown?

*Solution*

First calculate the water depth in the sounding line and the pumping water level:

$$\text{Water depth in sounding line} = 4.0 \text{ psi} \times 2.31 \text{ ft/psi}$$

$$= 9.2 \text{ ft}$$

$$\text{Pumping water level} = 180 \text{ ft} - 9.2 \text{ ft} = 170.8 \text{ ft}$$

Then calculate drawdown as usual:

$$\text{Drawdown (ft)} = \text{pumping water level (ft)} - \text{static water level (ft)}$$

$$= 170.8 \text{ ft} - 122 \text{ ft}$$

$$= 48.8 \text{ ft}$$

## Well Yield

*Well yield* is the volume of water per unit of time that is produced from the well pumping. Usually, well yield is measured in terms of gallons per minute (gpm) or gallons per hour (gph). Sometimes, large flows are measured in cubic feet per second (cfs). Well yield is determined by using the following equation.

$$\text{Well yield (gpm)} = \frac{\text{gallons produced}}{\text{duration of test (min)}} \tag{15.2}$$

### Example 15.3

*Problem*

Once the drawdown level of a well stabilized, it was determined that the well produced 400 gallons during a 5-minute test.

*Solution*

Referring to Equation 15.2:

$$\text{Well yield (gpm)} = \frac{400 \text{ gallons}}{5 \text{ minutes}}$$

$$= 80 \text{ gpm}$$

### Example 15.4

*Problem*

During a 5-minute test for well yield, a total of 780 gallons are removed from the well. What is the well yield in gpm? In gph?

*Solution*

$$\text{Well yield (gpm)} = \frac{\text{gallons removed}}{\text{duration of test (min)}}$$

$$= \frac{780 \text{ gallons}}{5 \text{ minutes}}$$

$$= 156 \text{ gpm}$$

Then convert gpm flow to gph flow:

$$156 \text{ gal/min} \times 60\text{/hr} = 9360 \text{ gph}$$

## Specific Yield

*Specific yield* is the discharge capacity of the well per foot of drawdown. The specific yield may range from 1 gpm/ft drawdown to more than 100-gpm/ft drawdown for a properly developed well. Specific yield is calculated using the equation:

$$\text{Specific yield (gpm/ft)} = \frac{\text{well yield (gpm)}}{\text{drawdown (ft)}} \tag{15.3}$$

### Example 15.5

*Problem*

A well produces 260 gpm. If the drawdown for the well is 22 ft, what is the specific yield in gpm/ft, and what is the specific yield in gpm/ft of drawdown?

*Solution*

Referring to Equation 15.3:

$$\begin{aligned} \text{Specific yield (gpm/ft)} &= \frac{260 \text{ gpm}}{22 \text{ ft}} \\ &= 11.8 \text{ gpm/ft} \end{aligned}$$

### Example 15.6

*Problem*

The yield for a particular well is 310 gpm. If the drawdown for this well is 30 ft, what is the specific yield in gpm/ft of drawdown?

*Solution*

Again referring to Equation 15.3:

$$\begin{aligned} \text{Specific yield (gpm/ft)} &= \frac{310 \text{ gpm}}{30 \text{ ft}} \\ &= 10.3 \text{ gpm/ft} \end{aligned}$$

## Well-Casing Disinfection

A new, cleaned, or a repaired well normally contains contamination that may remain for weeks unless the well is thoroughly disinfected. This may be accomplished by using ordinary bleach at a concentration of 100 parts per million (ppm) of chlorine. The amount of disinfectant required is determined by the amount of water in the well. The following equation is used to calculate the pounds of chlorine required for disinfection:

$$\text{Chlorine (lb)} = \text{Chlorine (mg/L)} \times \text{casing volume (MG)} \times 8.34 \text{ lb/gal} \tag{15.4}$$

**Example 15.7**

*Problem*

A new well is to be disinfected with chlorine at a dosage of 50 mg/L. If the well-casing diameter is 8 inches and the length of the water-filled casing is 110 ft, how many pounds of chlorine will be required?

*Solution*

First calculate the volume of the water-filled casing:

$$0.785 \times .67 \times 67 \times 110 \text{ ft} \times 7.48 \text{ gal/cu ft} = 290 \text{ gallons}$$

Then determine the pounds of chlorine required using the equation to convert mg/L to pounds (Equation 15.4):

$$50 \text{ mg/L} \times 0.000290 \text{ MG} \times 8.34 \text{ lb/gal} = 0.12 \text{ lb chlorine}$$

## Deep-Well Turbine Pump Calculations

The deep-well turbine pump is used for high-capacity deep wells. The pump, usually consisting of more than one stage of centrifugal pump, is fastened to a pipe called the *pump column*; the pump is located in the water. The pump is driven from the surface through a shaft running inside the pump column. The water is discharged from the pump up through the pump column to surface. The pump may be driven by a vertical shaft, electric motor at the top of the well, or some other power source, usually through a right-angle gear drive located at the top of the well. A modern version of the deep-well turbine pump is the submersible-type pump in which the pump, along with a close-coupled electric motor built as a single unit, is located below water level in the well. The motor is built to operate submerged in water.

## Vertical Turbine Pump Calculations

The calculations pertaining to well pumps include head, horsepower, and efficiency calculations. *Discharge head* is measured to the pressure gauge located closest to the pump discharge flange. The pressure (psi) can be converted to feet of head using the equation:

$$\text{Discharge head (ft)} = \text{pressure (psi)} \times 2.31 \text{ ft/psi} \tag{15.5}$$

*Total pumping head* or *field head* is a measure of the lift below the discharge head pumping water level (discharge head). Total pumping head is calculated as follows:

$$\text{Pumping head (ft)} = \text{pumping water level (ft)} + \text{discharge head (ft)} \tag{15.6}$$

**Example 15.8**

*Problem*

The pressure gauge reading at a pump discharge head is 4.1 psi. What is this discharge head expressed in feet?

*Solution*

$$4.1 \text{ psi} \times 2.31 \text{ ft/psi} = 9.5 \text{ ft}$$

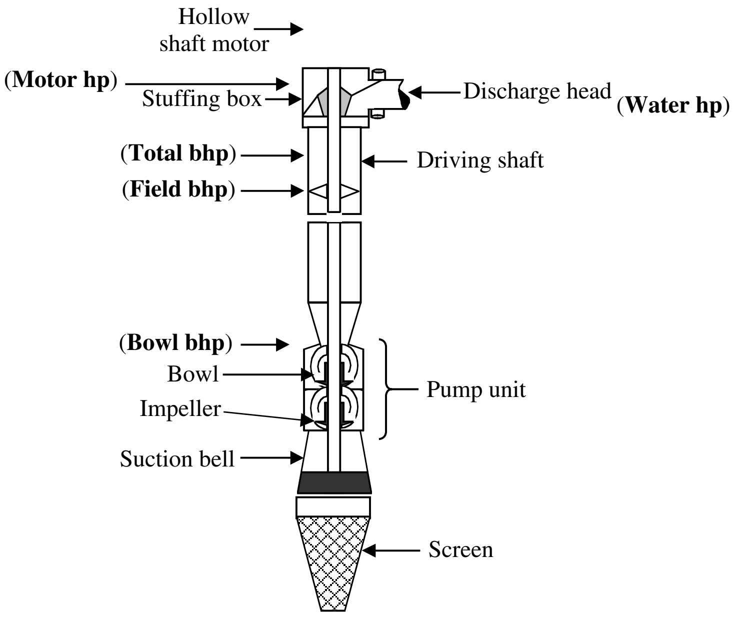


**FIGURE 15.2** Vertical turbine pump, showing five horsepower types.

### Example 15.9

*Problem*

The static water level of a pump is 100 ft. The well drawdown is 26 ft. If the gauge reading at the pump discharge head is 3.7 psi, what is the total pumping head?

*Solution*

Referring to Equation 15.6:

$$\begin{aligned}\text{Total pumping head (ft)} &= (100\text{ ft} + 26\text{ ft}) + (3.7\text{ psi} \times 2.31\text{ ft/psi})\\ &= 126\text{ ft} + 8.5\text{ ft} \qquad (15.7)\\ &= 134.5\text{ ft}\end{aligned}$$

We have five types of horsepower calculations for vertical turbine pumps (see Chapter 10 and Chapter 14). It is important to have a general understanding of these five horsepower types (refer to Figure 15.2):

- *Motor horsepower* refers to the horsepower supplied to the motor. Equation 15.8 is used to calculate motor horsepower:

$$\text{Motor hp (input hp)} = \frac{\text{field bhp}}{\dfrac{\text{motor efficiency}}{100}} \qquad (15.8)$$

- *Total brake horsepower* (bhp) refers to the horsepower output of the motor. Equation 15.9 is used to calculate total brake horsepower:

$$\text{Total bhp} = \text{field bhp} + \text{thrust bearing loss (hp)} \qquad (15.9)$$

- *Field horsepower* refers to the horsepower required at the top of the pump shaft. Equation 15.10 is used to calculate field horsepower:

$$\text{Field hp} = \text{bowl bhp} + \text{shaft loss (hp)} \tag{15.10}$$

- *Bowl or laboratory horsepower* refers to the horsepower at the entry to the pump bowls. Equation 15.11 is used to calculate bowl horsepower:

$$\text{Bowl bhp}\left(\text{lab bhp}\right) = \frac{\text{bowl head (ft)} \times \text{capacity}\left(\text{gpm}\right)}{3960 \times \dfrac{\text{bowl efficiency}}{100}} \tag{15.11}$$

- *Water horsepower* refers to the horsepower at the pump discharge. Equation 15.12 is used to calculate water horsepower:

$$\text{Water hp} = \frac{\text{field head (ft)} \times \text{capacity}\left(\text{gpm}\right)}{3960} \tag{15.12}$$

or the equivalent equation:

$$\text{Water hp} = \frac{\text{field head (ft)} \times \text{capacity}\left(\text{gpm}\right)}{33{,}000\ \text{ft-lb/min}}$$

### Example 15.10

*Problem*

The pumping water level for a well pump is 150 ft, and the discharge pressure measured at the pump discharge centerline is 3.5 psi. If the flow rate from the pump is 700 gpm, use Equation 15.12 to calculate the water horsepower.

*Solution*

First calculate the field head. The discharge head must be converted from psi to ft:

$$3.5 \text{ psi} \times 2.31 \text{ ft/psi} = 8.1 \text{ ft}$$

The water horsepower is therefore:

$$150 \text{ ft} + 8.1 \text{ ft} = 158.1 \text{ ft}$$

The water horsepower can now be determined:

$$\text{Water hp} = \frac{158.1 \text{ ft} \times 700 \text{ gpm} \times 8.34\ \text{lb/gal}}{33{,}000\ \text{ft-lb/min}}$$

$$= 28 \text{ whp}$$

### Example 15.11

*Problem*

The pumping water level for a pump is 170 ft. The discharge pressure measured at the pump discharge head is 4.2 psi. If the pump flow rate is 800 gpm, use Equation 15.12 to calculate the water horsepower.

*Solution*

The field head must first be determined. In order to determine field head, the discharge head must be converted from psi to ft:

$$4.2 \text{ psi} \times 2.31 \text{ ft/psi} = 9.7 \text{ ft}$$

The field head can now be calculated:

$$170 \text{ ft} + 9.7 \text{ ft} = 179.7 \text{ ft}$$

and then the water horsepower can be calculated:

$$\text{whp} = \frac{179.7 \text{ ft} \times 800 \text{ gpm}}{3960}$$

$$= 36 \text{ whp}$$

**Example 15.12**

*Problem*

A deep-well vertical turbine pump delivers 600 gpm. If the lab head is 185 feet and the bowl efficiency is 84%, use Equation 15.11 to calculate the bowl horsepower.

*Solution*

$$\text{Bowl bhp} = \frac{\text{bowl head (ft)} \times \text{capacity (gpm)}}{3960 \times \dfrac{\text{bowl efficiency}}{100}}$$

$$= \frac{185 \text{ ft} \times 600 \text{ gpm}}{3960 \times \dfrac{84.0}{100}}$$

$$= \frac{185 \times 600 \text{ gpm}}{3960 \times 0.84}$$

$$= 33.4 \text{ bowl bhp}$$

**Example 15.13**

*Problem*

A bowl bhp is 51.8 bhp. If a 1-inch diameter shaft is 170 ft long and is rotating at 960 rpm with a shaft fiction loss of 0.29 hp loss per 100 ft, what is the field bhp?

*Solution*

Before field bhp can be calculated, the shaft loss must be factored in:

$$\frac{0.29 \text{ hp loss}}{100} \times 170 \text{ ft} = 0.5 \text{ hp loss}$$

Now the field bhp can be determined:

$$\text{Field bhp} = \text{bowl bhp} + \text{shaft loss (hp)}$$

$$= 51.8 \text{ bhp} + 0.5 \text{ hp}$$

$$= 52.3 \text{ bhp}$$

**Example 15.14**

*Problem*

The field horsepower for a deep-well turbine pump is 62 bhp. If the thrust bearing loss is 0.5 hp and the motor efficiency is 88%, what is the motor input horsepower?

*Solution*

$$\text{mph} = \frac{\text{total bhp}}{\dfrac{\text{motor efficiency}}{100}}$$

$$= \frac{62 \text{ bhp} + 0.5 \text{ hp}}{0.88}$$

$$= 71 \text{ mhp}$$

When we speak of the *efficiency* of any machine, we are speaking primarily of a comparison of what is put out by the machine (e.g., energy output) compared to its input (e.g., energy input). Horsepower efficiency, for example, is a comparison of horsepower output of the unit or system with horsepower input to that unit or system — the efficiency of the unit. For vertical turbine pumps, four types of efficiencies are considered with vertical turbine pumps:

- Bowl efficiency
- Field efficiency
- Motor efficiency
- Overall efficiency

The general equation used to calculate percent efficiency is shown below:

$$\% = \frac{\text{part}}{\text{whole}} \times 100 \tag{15.13}$$

Vertical turbine pump *bowl efficiency* is easily determined using a pump performance curve chart provided by the pump manufacturer.

*Field efficiency* is determined by:

$$\text{Field efficiency } (\%) = \frac{\dfrac{\text{field head (ft)} \times \text{capacity (gpm)}}{3960}}{\text{total bhp}} \times 100 \tag{15.14}$$

**Example 15.15**

*Problem*

Given the data below, calculate the field efficiency of the deep-well turbine pump.

Field head = 180 ft
Capacity = 850 gpm
Total bhp = 61.3 bhp

*Solution*

Referring to Equation 15.14:

$$\text{Field efficiency } (\%) = \frac{180 \text{ ft} \times 850 \text{ gpm}}{3960 \times 61.3 \text{ bhp}} \times 100$$

$$= 63\%$$

The *overall efficiency* is a comparison of the horsepower output of the system with that entering the system. Equation 15.15 is used to calculate overall efficiency:

$$\text{Overall efficiency }(\%) = \frac{\text{field efficiency }(\%) \times \text{motor efficiency }(\%)}{100} \tag{15.15}$$

### Example 15.16

*Problem*

The efficiency of a motor is 90%. If the field efficiency is 83%, what is the overall efficiency of the unit?

*Solution*

Referring to Equation 15.15:

$$\begin{aligned}\text{Overall efficiency }(\%) &= \frac{\text{field efficiency }(\%) \times \text{motor efficiency }(\%)}{100} \times 100\% \\ &= \frac{83 \times 90}{100} \\ &= 74.9\%\end{aligned}$$

## WATER STORAGE

Water storage facilities for water distribution systems are required primarily to provide for fluctuating demands of water usage (to provide a sufficient amount of water to average or equalize daily demands on the water supply system). In addition, other functions of water storage facilities include increasing operating convenience, leveling pumping requirements (to keep pumps from running 24 hours a day), decreasing power costs, providing water during power source or pump failure, providing large quantities of water to meet fire demands, providing surge relief (to reduce the surge associated with stopping and starting pumps), increasing detention time (to provide chlorine contact time and satisfy the desired contact time [CT] value requirements), and blending water sources.

## WATER STORAGE CALCULATIONS

The storage capacity (in gallons) of a reservoir, pond, or small lake can be estimated (see Figure 15.3) using Equation 15.16.

$$\begin{aligned}\text{Reservoir, pond or lake capacity (gal)} &= \text{ave. length (ft)} \times \text{ave. width (ft)} \times \\ &\quad \text{ave. depth (ft)} \times 7.48 \text{ gal/cu ft}\end{aligned} \tag{15.16}$$

### Example 15.17

*Problem*

A pond has an average length of 250 ft, an average width of 110 ft, and an estimated average depth of 15 ft. What is the estimated volume of the pond in gallons?

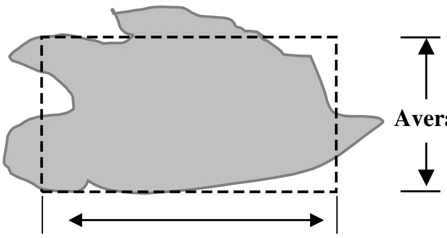


**FIGURE 15.3** Determining pond storage capacity.

*Solution*

Referring to Equation 15.16:

$$\text{Volume (gal)} = 250 \text{ ft} \times 110 \text{ ft} \times 15 \text{ ft} \times 7.48 \text{ gal/cu ft}$$

$$= 3{,}085{,}500 \text{ gal}$$

### Example 15.18

*Problem*

A small lake has an average length of 300 ft and an average width of 95 ft. If the maximum depth of the lake is 22 ft, what is the estimated gallons volume of the lake?

> ✓ **Note:** For small ponds and lakes, the average depth is generally about 0.4 times the greatest depth; therefore, to estimate the average depth, measure the greatest depth and multiply that number by 0.4.

*Solution*

First, the average depth of the lake must be estimated:

$$\text{Estimated average depth (ft)} = \text{greatest depth (ft)} \times 0.4 \text{ depth (ft)}$$

$$= 22 \text{ ft} \times 0.4 \text{ ft}$$

$$= 8.8 \text{ ft}$$

The lake volume can then be determined using Equation 15.16:

$$\text{Volume (gal)} = 300 \text{ ft} \times 95 \text{ ft} \times 8.8 \text{ ft} \times 7.48 \text{ cu ft}$$

$$= 1{,}875{,}984 \text{ gal}$$

## COPPER SULFATE DOSING

Algal control, perhaps the most common *in situ* treatment of lakes, ponds, and reservoirs, is achieved by application of copper sulfate; the copper ions in the water kill the algae. Copper sulfate application methods and dosages will vary depending on the specific surface water body being

treated. The desired copper sulfate dosage may be expressed in mg/L copper, lb copper sulfate/ac-ft, or lb copper sulfate/ac.

For a dose expressed as mg/L copper, the following equation is used to calculate lb copper sulfate required:

$$\text{Copper sulfate (lb)} = \frac{\text{copper (mg/L)} \times \text{volume (MG)} \times 8.34 \text{ lb/gal}}{\frac{\text{\% available copper}}{100}} \tag{15.17}$$

**Example 15.19**

*Problem*

For algae control in a small pond, a dosage of 0.5 mg/L copper is desired. The pond has a volume of 15 MG. How many pounds of copper sulfate will be required? (Copper sulfate contains 25% available copper.)

*Solution*

Referring to Equation 15.17:

$$\text{Copper sulfate (lb)} = \frac{0.5 \text{ mg/L} \times 15 \text{ MG} \times 8.34 \text{ lb/gal}}{\frac{25}{100}}$$

$$= 250 \text{ lb copper sulfate}$$

For calculating pounds copper sulfate/acre-ft, use the following equation (assume the desired copper sulfate dosage is 0.9 lb/ac-ft):

$$\text{Copper sulfate (lb)} = \frac{0.9 \text{ lb copper sulfate} \times \text{ac-ft}}{1 \text{ ac-ft}} \tag{15.18}$$

**Example 15.20**

A pond has a volume of 35 ac-ft. If the desired copper sulfate dose is 0.9 lb/ac-ft, how many lb of copper sulfate will be required?

*Solution*

Set up a ratio using Equation 15.18:

$$\frac{0.9 \text{ lb copper sulfate}}{1 \text{ ac-ft}} = \frac{x \text{ lb copper sulfate}}{35 \text{ ac-ft}}$$

Then solve for $x$:

$$x = 0.9 \times 35$$

$$x = 31.5 \text{ lb copper sulfate}$$

The desired copper sulfate dosage may also be expressed in terms of lb copper sulfate/acre. The following equation is used to determine lb copper sulfate (assume a desired dose of 5.2 lb copper sulfate/ac):

$$\text{Copper sulfate (lb)} = \frac{5.2 \text{ lb copper sulfate} \times \text{ac}}{1 \text{ ac}} \tag{15.19}$$

**Example 15.21**

*Problem*

A small lake has a surface area of 6.0 acres. If the desired copper sulfate dose is 5.2 lb/ac, how many pounds of copper sulfate are required?

*Solution*

$$\text{Copper sulfate (lb)} = \frac{5.2 \text{ lb copper sulfate} \times 6.0 \text{ ac}}{1 \text{ ac}}$$

$$= 31.2 \text{ lb copper sulate}$$

# 16 Coagulation and Flocculation Calculations

## TOPICS



## COAGULATION

Following screening and the other pretreatment processes, the next unit process in a conventional water treatment system is mixing, when chemicals are added during what is known as coagulation. The exception to this situation occurs in small systems using groundwater, where chlorine or other taste and odor control measures are often introduced at the intake and are the extent of treatment. The term *coagulation* refers to the series of chemical and mechanical operations by which coagulants are applied and made effective. These operations are comprised of two distinct phases: (1) rapid mixing to disperse coagulant chemicals by violent agitation into the water being treated, and (2) flocculation to agglomerate small particles into well-defined floc by gentle agitation for a much longer time. The coagulant must be added to the raw water and perfectly distributed into the liquid; such uniformity of chemical treatment is reached through rapid agitation or mixing. Coagulation results from adding salts of iron or aluminum to the water and is a reaction between one of the following (coagulants) salts and water:

- Alum — aluminum sulfate
- Sodium aluminate
- Ferric sulfate
- Ferrous sulfate
- Ferric chloride
- Polymers

## FLOCCULATION

Flocculation follows coagulation in the conventional water treatment process. Flocculation is the physical process of slowly mixing the coagulated water to increase the probability of particle collision. Through experience, we see that effective mixing reduces the required amount of chemicals and greatly improves the sedimentation process, which results in longer filter runs and higher quality finished water. The goal of flocculation is to form a uniform, feather-like material similar to snowflakes — a dense, tenacious *floc* that entraps the fine, suspended, and colloidal particles and carries them down rapidly in the settling basin. To increase the speed of floc formation and the strength and weight of the floc, polymers are often added.

## COAGULATION AND FLOCCULATION CALCULATIONS

Calculations are performed during operation of the coagulation and flocculation unit processes to determine chamber or basin volume, chemical feed calibration, chemical feeder settings, and detention time.

### CHAMBER AND BASIN VOLUME CALCULATIONS

To determine the volume of a square or rectangular chamber or basin, we use:

$$\text{Volume (cu ft)} = \text{length (ft)} \times \text{width (ft)} \times \text{depth (ft)} \tag{16.1}$$

$$\text{Volume (gal)} = \text{length (ft)} \times \text{width (ft)} \times \text{depth (ft)} \times 7.48 \text{ gal/cu ft} \tag{16.2}$$

**Example 16.1**

*Problem*

A flash mix chamber is 4 ft square with water to a depth of 3 ft. What is the volume of water (in gallons) in the chamber?

*Solution*

Referring to Equation 16.2:

$$\text{Volume (gal)} = 4 \text{ ft} \times 4 \text{ ft} \times 3 \text{ ft} \times 7.48 \text{ gal/cu ft}$$

$$= 359 \text{ gal}$$

**Example 16.2**

*Problem*

A flocculation basin is 40 ft long and 12 ft wide and has water to a depth of 9 ft. What is the volume of water (in gallons) in the basin?

*Solution*

Referring to Equation 16.2:

$$\text{Volume (gal)} = 40 \text{ ft} \times 12 \text{ ft} \times 9 \text{ ft} \times 7.48 \text{ gal/cu ft}$$

$$= 32{,}314 \text{ gal}$$

### Example 16.3

*Problem*

A flocculation basin is 50 ft long, 22 ft wide, and contains water to a depth of 11 ft 6 in. How many gallons of water are in the tank?

*Solution*

First convert the 6-inch portion of the depth measurement to feet:

$$\frac{6 \text{ in.}}{12 \text{ in./ft}} = 0.5 \text{ ft}$$

Then use Equation 16.2 to calculate basin volume:

$$\begin{aligned} \text{Volume (ft)} &= 50 \text{ ft} \times 22 \text{ ft} \times 11.5 \text{ ft} \times 7.48 \text{ gal/cu ft} \\ &= 94{,}622 \text{ gal} \end{aligned}$$

## Detention Time

Because coagulation reactions are rapid, detention time for flash mixers is measured in seconds, whereas the detention time for flocculation basins is generally between 5 and 30 minutes. The equation used to calculate detention time is shown below.

$$\text{Detention time (min)} = \frac{\text{volume of tank (gal)}}{\text{flow rate (gpm)}} \tag{16.3}$$

### Example 16.4

*Problem*

The flow to a flocculation basin 50 ft long, 12 ft wide, and 10 ft deep is 2100 gpm. What is the detention time in the tank (in minutes)?

*Solution*

$$\begin{aligned} \text{Tank volume (gal)} &= 50 \text{ ft} \times 12 \text{ ft} \times 10 \text{ ft} \times 7.48 \text{ gal/cu ft} \\ &= 44{,}880 \text{ gal} \end{aligned}$$

Then apply Equation 16.3:

$$\begin{aligned} \text{Detention time (min)} &= \frac{44{,}880 \text{ gal}}{2100 \text{ gpm}} \\ &= 21.4 \text{ min} \end{aligned}$$

### Example 16.5

*Problem*

Assume the flow is steady and continuous for a flash mix chamber 6 ft long and 4 ft wide with water to a depth of 3 ft. If the flow to the flash mix chamber is 6 MGD, what is the chamber detention time (in seconds)?

*Solution*

First, convert the flow rate from gpd to gps so the time units will match:

$$\frac{6{,}000{,}000}{1440\ \text{min/day} \times 60\ \text{sec/min}} = 69\ \text{gps}$$

Then calculate detention time using Equation 16.3:

$$\text{Detention time (sec)} = \frac{6\ \text{ft} \times 4\ \text{ft} \times 3\ \text{ft} \times 7.48\ \text{gal/cu ft}}{69\ \text{gps}}$$

$$= 7.8\ \text{sec}$$

## Determining Dry Chemical Feeder Setting (lb/d)

When adding (dosing) chemicals to the water flow, a measured amount of chemical is required that depends on such factors as the type of chemical used, the reason for dosing, and the flow rate being treated. To convert from mg/L to lb/day, the following equation is used:

$$\text{Chemical added (lb/day)} = \text{chemical (mg/L)} \times \text{flow (MGD)} \times 8.34\ \text{lb/gal} \tag{16.4}$$

### Example 16.6

*Problem*

Jar tests indicate that the best alum dose for a water is 8 mg/L. If the flow to be treated is 2,100,000 gpd, what should the lb/day setting be on the dry alum feeder?

*Solution*

Referring to Equation 16.4:

$$\text{Chemical added (lb/d)} = 8\ \text{mg/L} \times 2.10\ \text{MGD} \times 8.34\ \text{lb/gal}$$

$$= 140\ \text{lb/day}$$

### Example 16.7

*Problem*

Determine the desired pounds per day setting on a dry chemical feeder if jar tests indicate an optimum polymer dose of 12 mg/L and the flow to be treated is 4.15 MGD.

*Solution*

$$\text{Polymer (lb/day)} = 12\ \text{mg/L} \times 4.15\ \text{MGD} \times 8.34\ \text{lb/gal}$$

$$= 415\ \text{lb/day}$$

## Determining Chemical Solution Feeder Setting (gpd)

When solution concentration is expressed as lb chemical/gal solution, the required feed rate can be determined using the following equation:

$$\text{Chemical (lb/d)} = \text{Chemical (mg/L)} \times \text{flow (MGD)} \times 8.34\ \text{lb/gal} \tag{16.5}$$

Then convert the lb/day dry chemical to gpd solution

$$\text{Solution (gpd)} = \frac{\text{chemical (lb/day)}}{\text{lb chemical/gal solution}} \tag{16.6}$$

**Example 16.8**

*Problem*

Jar tests indicate that the best alum dose for a water is 7 mg/L. The flow to be treated is 1.52 MGD. Determine the gallons per day setting for the alum solution feeder if the liquid alum contains 5.36 lb of alum per gallon of solution.

*Solution*

First calculate the lb/d of dry alum required, using Equation 16.5:

$$\text{Dry alum (lb/day)} = 7 \text{ mg/L} \times 1.52 \text{ MGD} \times 8.34 \text{ lb/gal}$$

$$= 89 \text{ lb/day}$$

Then calculate the gpd solution required:

$$\text{Alum solution (gpd)} = \frac{89 \text{ lb/day}}{5.36 \text{ lb alum/gal solution}}$$

$$= 16.6 \text{ gpd}$$

## Determining Chemical Solution Feeder Setting (mL/min)

Some solution chemical feeders dispense chemical as milliliters per minute (mL/min). To calculate the mL/min solution required, use the following procedure:

$$\text{Solution (mL/min)} = \frac{\text{gpd} \times 3785 \text{ mL/gal}}{1440 \text{ min/day}} \tag{16.7}$$

**Example 16.9**

*Problem*

The desired solution feed rate was calculated to be 9 gpd. What is this feed rate expressed as mL/min?

*Solution*

Referring to Equation 16.7:

$$\text{Feed rate (mL/min)} = \frac{9 \text{ gpd} \times 3785 \text{ mL/gal}}{1440 \text{ min/day}}$$

$$= 24 \text{ mL/min}$$

**Example 16.10**

*Problem*

The desired solution feed rate has been calculated to be 25 gpd. What is this feed rate expressed as mL/min?

*Solution*

Referring to Equation 16.7:

$$\text{Feed rate}\left(\text{mL/min}\right) = \frac{25\ \text{gpd} \times 3785\ \ \text{mL/gal}}{1440\ \ \text{min/day}}$$

$$= 65.7\ \ \text{mL/min}$$

Sometimes we will need to know mL/min solution feed rate but we will not know the gpd solution feed rate. In such cases, calculate the gpd solution feed rate first, using the following the equation:

$$\text{Feed rate}\left(\text{gpd}\right) = \frac{\text{chemical}\left(\text{mg/L}\right) \times \text{flow (MGD)} \times 8.34\ \ \text{lb/gal}}{\text{chemical (lb)/solution}\left(\text{gal}\right)} \tag{16.8}$$

### Determining Percent of Solutions

The strength of a solution is a measure of the amount of chemical solute dissolved in the solution. We use the following equation to determine % strength of solution using the following equation:

$$\%\ \text{Strength} = \frac{\text{chemical (lb)}}{\text{water (lb)} + \text{chemical (lb)}} \times 100 \tag{16.9}$$

**Example 16.11**

*Problem*

If a total of 10 ounces of dry polymer is added to 15 gallons of water, what is the percent strength (by weight) of the polymer solution?

*Solution*

Before calculating percent strength, the ounces chemical must be converted to lb chemical:

$$\frac{10\ \text{ounces}}{16\ \ \text{ounces/pound}} = 0.625\ \text{lb chemical}$$

Now calculate percent strength using Equation 16.9:

$$\%\ \text{Strength} = \frac{0.625\ \text{lb chemical}}{15\ \text{gal} \times 8.34\ \text{lb/gal}} \times 0.625\ \text{lb}$$

$$= \frac{0.625\ \text{lb chemical}}{125.7\ \text{lb solution}} \times 100$$

$$= 0.5\%$$

**Example 16.12**

*Problem*

If 90 grams (1 gram = 0.0022 lb) of dry polymer are dissolved in 6 gallons of water, what percent strength is the solution?

*Solution*

First, convert grams chemical to pounds chemical. Because 1 gram = 0.0022 lb, 90 grams = 90 × 0.0022 lb:

$$90 \text{ grams polymer} \times 0.0022 \text{ lb/gram} = 0.198 \text{ lb polymer}$$

Now calculate percent strength of the solution:

$$\begin{aligned}
\% \text{ Strength} &= \frac{\text{lb polymer}}{\text{lb water} + \text{lb polymer}} \times 100 \\
&= \frac{0.198 \text{ lb polymer}}{(6 \text{ gal} \times 8.34 \text{ lb/gal}) + 0.198 \text{ lb}} \times 100 \\
&= 4\%
\end{aligned}$$

## Determining Percent Strength of Liquid Solutions

When using liquid chemicals to make up solutions (e.g., liquid polymer), a different calculation is required, as shown below:

$$\text{Liq. poly. (lb)} \times \frac{\text{liq. poly. (\% strength)}}{100} = \text{poly. sol. (lb)} \frac{\text{poly. sol. (\% strength)}}{100} \qquad (16.10)$$

### Example 16.13

*Problem*

A 12% liquid polymer is to be used in making up a polymer solution. How many pounds of liquid polymer should be mixed with water to produce 120 lb of a 0.5% polymer solution?

*Solution*

Referring to Equation 16.10:

$$\begin{aligned}
x \text{ lb} \times \frac{12}{100} &= 120 \text{ lb} \times \frac{0.5}{100} \\
x &= \frac{120 \times 0.05}{0.12} \\
x &= 5 \text{ lb}
\end{aligned}$$

## Determining Percent Strength of Mixed Solutions

The percent strength of solution mixture is determined using the following equation:

$$\% \text{ Strength of mix.} = \frac{\dfrac{\text{sol. 1 (lb)} \times \text{\% strength of sol. 1}}{100} + \dfrac{\text{sol. 2 (lb)} \times \text{\% strength of sol. 2}}{100}}{\text{lb solution 1} + \text{lb solution 2}} \times 100 \qquad (16.11)$$

**Example 16.14**

*Problem*

If 12 lb of a 10% strength solution are mixed with 40 lb of 1% strength solution, what is the percent strength of the solution mixture?

*Solution*

Referring to Equation 16.11:

$$\% \text{ Strength of mixture} = \frac{(12 \text{ lb} \times 0.1) + (40 \text{ lb} \times 0.01)}{12 \text{ lb} + 40 \text{ lb}} \times 100$$

$$= \frac{1.2 \text{ lb} + 0.40}{52 \text{ lb}} \times 100$$

$$= 3.1\%$$

## Dry Chemical Feeder Calibration

Occasionally we need to perform a calibration calculation to compare the actual chemical feed rate with the feed rate indicated by the instrumentation. To calculate the actual feed rate for a dry chemical feeder, place a container under the feeder, weigh the container when empty, then weigh the container again after a specified length of time (e.g., 30 minutes). The actual chemical feed rate can be calculated using the following equation:

$$\text{Chemical feed rate (lb/min)} = \frac{\text{chemical applied (lb)}}{\text{length of application (min)}} \tag{16.12}$$

If desired, the chemical feed rate can be converted to lb/d:

$$\text{Feed rate (lb/day)} = \text{Feed rate (lb/min)} \times 1440 \text{ min/day} \tag{16.13}$$

**Example 16.15**

*Problem*

Calculate the actual chemical feed rate (lb/day) if a container is placed under a chemical feeder and a total of 2 lb is collected during a 30-minute period.

*Solution*

First calculate the lb/min feed rate using Equation 16.12:

$$\text{Chemical feed rate (lb/min)} = \frac{2 \text{ lb}}{30 \text{ min}}$$

$$= 0.07 \text{ lb/min}$$

Then calculate the lb/day feed rate using Equation 16.13:

$$\text{Chemical feed rate (lb/day)} = 0.06 \text{ lb/min} \times 1440 \text{ min/day}$$

$$= 86.4 \text{ lb/day}$$

**Example 16.16**

*Problem*

Calculate the actual chemical feed rate (lb/day) if a container is placed under a chemical feeder and a total of 1.6 lb is collected during a 20-minute period.

*Solution*

First calculate the lb/min feed rate using Equation 16.12:

$$\text{Chemical feed rate } (\text{lb/min}) = \frac{1.6 \text{ lb}}{20 \text{ min}}$$

$$= 0.08 \text{ lb/min}$$

Then calculate the lb/day feed rate:

$$\text{Chemical feed rate (lb/day)} = 0.08 \text{ lb/min} \times 1440 \text{ min/day}$$

$$= 115 \text{ lb/day}$$

### Solution Chemical Feeder Calibration

As with other calibration calculations, the actual solution chemical feed rate is determined and then compared with the feed rate indicated by the instrumentation. To calculate the actual solution chemical feed rate, first express the solution feed rate in MGD. Once the MGD solution flow rate has been calculated, use the mg/L in Equation 16.15 to determine chemical dosage in lb/d. If solution feed is expressed as mL/min, first convert the mL/min flow rate to a gpd flow rate:

$$\text{gpd} = \frac{\text{mL/min} \times 1440 \text{ min/day}}{3785 \text{ mL/gal}} \tag{16.14}$$

Then calculate chemical dosage, lb/day.

$$\text{Chemical (lb/day)} = \text{chemical (mg/L)} \times \text{flow (MGD)} \times 8.34 \text{ lb/day} \tag{16.15}$$

**Example 16.17**

*Problem*

A calibration test was conducted for a solution chemical feeder. During a 5-minute test, the pump delivered 940 mg/L of the 1.20% polymer solution. What is the polymer dosage rate in lb/day? (Assume the polymer solution weighs 8.34 lb/gal.)

*Solution*

The flow rate must be expressed as MGD; therefore, the mL/min solution flow rate must first be converted to gpd and then MGD. The mL/min flow rate is calculated as:

$$\frac{940 \text{ mL}}{5 \text{ min}} = 188 \text{ mL/min}$$

Next convert the mL/min flow rate to gpd flow rate:

$$\text{Flow rate} = \frac{188 \text{ mL/min} \times 1440 \text{ min/day}}{3785 \text{ mL/gal}}$$

$$= 72 \text{ gpd}$$

Then calculate the lb/d polymer feed rate:

$$\text{Feed rate} = 12{,}000 \text{ mg/L} \times 0.000072 \text{ MGD} \times 8.34 \text{ lb/day}$$

$$= 7.2 \text{ lb/day polymer}$$

**Example 16.18**

*Problem*

A calibration test is conducted for a solution chemical feeder. During a 24-hour period, the solution feeder delivers a total of 100 gal of solution. The polymer solution is a 1.2% solution. What is the lb/day feed rate? (Assume the polymer solution weighs 8.34 lb/gal.)

*Solution*

The solution feed rate is 100 gallons per day (gpd). Expressed as MGD, this is 0.000100 MGD. Use Equation 16.15 to calculate actual feed rate in lb/day:

$$\text{Feed rate (lb/day)} = 12{,}000 \text{ mg/L} \times 0.000100 \text{ MGD} \times 8.34 \text{ lb/day}$$

$$= 10 \text{ lb/day polymer}$$

The actual pumping rates can be determined by calculating the volume pumped during a specified time frame. For example, if 60 gallons are pumped during a 10-minute test, the average pumping rate during the test is 6 gpm.

Actual volume pumped is indicated by a drop in tank level. By using the following equation, we can determine the flow rate in gpm.

$$\text{Flow rate (gpm)} = \frac{0.785 \times D^2 \times \text{drop in level (ft)} \times 7.48 \text{ gal/cu ft}}{\text{duration of test (min)}} \tag{16.16}$$

**Example 16.19**

*Problem*

A pumping rate calibration test is conducted for a 15-minute period. The liquid level in the 4-ft diameter solution tank is measured before and after the test. If the level drops 0.5 ft during the 15-min test, what is the pumping rate in gpm?

*Solution*

Referring to Equation 16.16:

$$\text{Flow rate (gpm)} = \frac{0.785 \times 4 \text{ ft} \times 4 \text{ ft} \times 0.5 \text{ ft} \times 7.48 \text{ gal/cu ft}}{15 \text{ min}}$$

$$= 3.1 \text{ gpm pumping rate}$$

### Determining Chemical Usage

One of the primary functions performed by water operators is the recording of data. Chemical use in lb/day or gpd is part of the data. From the data, the average daily use of chemicals and solutions can be determined. This information is important in forecasting expected chemical use by comparing it with chemicals in inventory and determining when additional chemicals will be required. To determine average chemical use, we use Equation 16.17 for lb/d or Equation 16.18 for gpd.

$$\text{Average use (lb/day)} = \frac{\text{total chemical used (lb)}}{\text{number of days}} \tag{16.17}$$

or

$$\text{Average use (gpd)} = \frac{\text{total chemical used (gal)}}{\text{number of days}} \tag{16.18}$$

Then we can calculate the number of days of supply in inventory:

$$\text{Day's supply in inventory} = \frac{\text{total chemical in inventory (lb)}}{\text{average use (lb/day)}} \tag{16.19}$$

or

$$\text{Day's supply in inventory} = \frac{\text{total chemical in inventory (gal)}}{\text{average use (gpd)}} \tag{16.20}$$

#### Example 16.20

*Problem*

The chemical used for each day during a week is given below. Based on the data, what was the average lb/day chemical use during the week?

| | |
|---|---|
| Monday: 88 lb/day | Friday: 96 lb/day |
| Tuesday: 93 lb/day | Saturday: 92 lb/day |
| Wednesday: 91 lb/day | Sunday: 86 lb/day |
| Thursday: 88 lb/day | |

*Solution*

Referring to Equation 16.17:

$$\text{Average use (lb/day)} = \frac{634\text{ lb}}{7\text{ days}}$$

$$= 90.6\ \text{lb/day}$$

#### Example 16.21

The average chemical use at a plant is 77 lb/day. If the chemical inventory is 2800 lb, how many days of supply is this?

*Solution*

Referring to Equation 16.19:

$$\text{Days' supply in inventory} = \frac{2800 \text{ lb}}{77 \text{ lb/day}}$$

$$= 36.4 \text{ days}$$

# 17 Sedimentation Calculations

## TOPICS



## SEDIMENTATION

Sedimentation, the separation of solids and liquids by gravity, is one of the most basic processes of water and wastewater treatment. In water treatment, plain sedimentation, such as the use of a presedimentation basin for grit removal and sedimentation basin following coagulation–flocculation, is the most commonly used.

## TANK VOLUME CALCULATIONS

The two most common tank shapes of sedimentation tanks are rectangular and cylindrical. The equations for calculating the volumes for these shapes are shown in Equation 17.1 and Equation 17.2.

### Calculating Tank Volume

For rectangular sedimentation basins, we use:

$$\text{Volume (gal)} = \text{length (ft)} \times \text{width (ft)} \times \text{depth (ft)} \times 7.48 \text{ gal/cu ft} \tag{17.1}$$

For cylindrical clarifiers, we use:

$$\text{Volume (gal)} = 0.785 \times D^2 \times \text{depth (ft)} \times 7.48 \text{ gal/cu ft} \tag{17.2}$$

**Example 17.1**

*Problem*

A sedimentation basin is 25 ft wide by 80 ft long and contains water to a depth of 14 ft. What is the volume of water in the basin (in gallons)?

*Solution*

Referring to Equation 17.1:

$$\text{Volume (gal)} = 80\text{ ft} \times 25\text{ ft} \times 14\text{ ft} \times 7.48\text{ gal/cu ft}$$

$$= 209{,}440\text{ gal}$$

**Example 17.2**

*Problem*

A sedimentation basin is 24 ft wide by 75 ft long. When the basin contains 140,000 gallons, what would the water depth be?

*Solution*

Referring to Equation 17.1:

$$140{,}000\text{ gal} = 75\text{ ft} \times 24\text{ ft} \times x\text{ ft} \times 7.48\text{ gal/cu ft}$$

$$x\text{ ft} = \frac{140{,}000}{75 \times 24 \times 7.48}$$

$$x\text{ ft} = 10.4\text{ ft}$$

## DETENTION TIME

Detention time for clarifiers varies from 1 to 3 hours. The equations used to calculate detention time are shown below.

- *Basic detention time equation:*

$$\text{Detention time (hr)} = \frac{\text{volume of tank (gal)}}{\text{flow rate (gph)}} \tag{17.3}$$

- *Rectangular sedimentation basin equation:*

$$\text{Detention time (hr)} = \frac{\text{length (ft)} \times \text{width (ft)} \times \text{depth (ft)} \times 7.48\text{ gal/cu ft}}{\text{flow rate (gph)}} \tag{17.4}$$

- *Circular basin equation:*

$$\text{Detention time (hr)} = \frac{0.785 \times D^2 \times \text{depth (ft)} \times 7.48\text{ gal/cu ft}}{\text{flow rate (gph)}} \tag{17.5}$$

**Example 17.3**

*Problem*

A sedimentation tank has a volume of 137,000 gallons. If the flow to the tank is 121,000 gph, what is the detention time in the tank (in hours)?

*Solution*

Referring to Equation 17.3:

$$\text{Detention time (hr)} = \frac{137{,}000 \text{ gal}}{121{,}000 \text{ gph}}$$

$$= 1.1 \text{ hours}$$

**Example 17.4**

*Problem*

A sedimentation basin is 60 ft long by 22 ft wide and has water to a depth of 10 ft. If the flow to the basin is 1,500,000 gpd, what is the sedimentation basin detention time?

*Solution*

First, convert the flow rate from gpd to gph so the time units match:

$$1{,}500{,}000 \text{ gpd} \div 24 \text{ hr/day} = 62{,}500 \text{ gph}$$

Then calculate detention time using Equation 17.5:

$$\text{Detention time (hr)} = \frac{60 \text{ ft} \times 22 \text{ ft} \times 10 \text{ ft} \times 7.48 \text{ gal/cu ft}}{62{,}500 \text{ gph}}$$

$$= 1.6 \text{ hours}$$

## SURFACE OVERFLOW RATE

Surface loading rate — similar to hydraulic loading rate (flow per unit area) — is used to determine loading on sedimentation basins and circular clarifiers. Hydraulic loading rate, however, measures the total water entering the process, whereas surface overflow rate measures only the water overflowing the process (plant flow only).

✔ **Note:** Surface overflow rate calculations do not include recirculated flows. Other terms used synonymously with surface overflow rate are *surface loading rate* and *surface settling rate*.

Surface overflow rate is determined using the following equation:

$$\text{Surface overflow rate} = \frac{\text{flow (gpm)}}{\text{area } (\text{ft}^2)} \tag{17.6}$$

**Example 17.5**

*Problem*

A circular clarifier has a diameter of 80 ft. If the flow to the clarifier is 1800 gpm, what is the surface overflow rate in gpm/sq ft?

*Solution*

Referring to Equation 17.6:

$$\text{Surface overflow rate} = \frac{1800 \text{ gpm}}{0.785 \times 80 \text{ ft} \times 80 \text{ ft}}$$

$$= 0.36 \text{ gpm/sq ft}$$

**Example 17.6**

*Problem*

A sedimentation basin that is 70 ft by 25 ft receives a flow of 1000 gpm. What is the surface overflow rate in gpm/sq ft?

*Solution*

Referring to Equation 17.6:

$$\text{Surface overflow rate} = \frac{1000 \text{ gpm}}{70 \text{ ft} \times 25 \text{ ft}}$$

$$= 0.6 \text{ gpm/sq ft}$$

## MEAN FLOW VELOCITY

The measure of average velocity of the water as it travels through a rectangular sedimentation basin is known as mean flow velocity. Mean flow velocity is calculated by:

$$Q\,(\text{flow, cu ft/min}) = A\,(\text{cross-sectional area, ft}^2) \times V\,(\text{volume, ft/min})$$
$$Q = A \times V \tag{17.7}$$

**Example 17.7**

*Problem*

A sedimentation basin that is 60 ft long by 18 ft wide has water to a depth of 12 ft. When the flow through the basin is 900,000 gpd, what is the mean flow velocity in the basin (in ft/min)?

*Solution*

Because velocity is desired in ft/min, the flow rate in the $Q = A \times V$ equation must be expressed in cu ft/min (cfm):

$$\frac{900{,}000 \text{ gpd}}{1440 \text{ min/day} \times 7.48 \text{ gal/cu ft}} = 84 \text{ cfm}$$

Then use the $Q = A \times V$ equation to calculate velocity:

$$84 \text{ cfm} = 18 \text{ ft} \times 12 \text{ ft} \times x \text{ fpm}$$

$$x = \frac{84}{18 \times 12}$$

$$= 0.4 \text{ fpm}$$

**Example 17.8**

*Problem*

A rectangular sedimentation basin that is 50 ft long and 20 ft wide has a water depth of 9 ft. If the flow to the basin is 1,880,000 gpd, what is the mean flow velocity (in ft/min)?

*Solution*

Because velocity is desired in ft/min, the flow rate in the $Q = A \times V$ equation must be expressed in cu ft/min (cfm):

$$\frac{1{,}880{,}000 \text{ gpd}}{1440 \text{ min/day} \times 7.48 \text{ gal/cu ft}} = 175 \text{ cfm}$$

Then use the $Q = A \times V$ equation to calculate velocity:

$$175 \text{ cfm} = 20 \text{ ft} \times 9 \text{ ft} \times x \text{ fpm}$$

$$x = \frac{175 \text{ cfm}}{20 \times 9}$$

$$x = 0.97 \text{ fpm}$$

## WEIR LOADING RATE (WEIR OVERFLOW RATE)

Weir loading rate (weir overflow rate) is the amount of water leaving the settling tank per linear foot of weir. The result of this calculation can be compared with design. Normally, weir overflow rates of 10,000 to 20,000 gallon/day/foot are used in the design of a settling tank. Typically, weir-loading rate is a measure of the gallon per minute (gpm) flow over each foot (ft) of weir. Weir loading rate is determined using the following equation:

$$\text{Weir loading rate (gpm/ft)} = \frac{\text{flow (gpm)}}{\text{Weir length (ft)}} \tag{17.8}$$

**Example 17.9**

*Problem*

A rectangular sedimentation basin has a total of 115 ft of weir. What is the weir loading rate in gpm/ft$^2$ when the flow is 1,110,000 gpd?

*Solution*

$$\frac{1{,}110{,}000 \text{ gpd}}{1440 \text{ min/day}} = 771 \text{ gpm}$$

Referring to Equation 17.8:

$$\text{Weir loading rate} = \frac{771 \text{ gpm}}{115 \text{ ft}}$$

$$= 6.7 \text{ gpm/ft}$$

**Example 17.10**

*Problem*

A circular clarifier receives a flow of 3.55 MGD. If the diameter of the weir is 90 ft, what is the weir-loading rate (in gpm/ft)?

*Solution*

$$\frac{3{,}550{,}000 \text{ gpd}}{1440 \text{ min/day}} = 2465 \text{ gpm}$$

$$\text{ft of weir} = 3.14 \times 90 \text{ ft}$$

$$= 283 \text{ ft}$$

Referring to Equation 17.8:

$$\text{Weir loading rate} = \frac{\text{Flow (gpm)}}{\text{Weir length (ft)}}$$

$$= \frac{2465 \text{ gpm}}{283 \text{ ft}}$$

$$= 8.7 \text{ gpm/ft}$$

## PERCENT SETTLED BIOSOLIDS

The percent settled biosolids test (also referred to as *volume over volume* test, or *V/V test*) is conducted by collecting a 100-mL slurry sample from the solids contact unit and allowing it to settle for 10 minutes. After 10 minutes, the volume of settled biosolids at the bottom of the 100-mL graduated cylinder is measured and recorded. The equation used to calculate percent settled biosolids is shown below:

$$\% \text{ Settled biosolids} = \frac{\text{settled biosolids volume (mL)}}{\text{total sample volume (mL)}} \times 100 \tag{17.9}$$

**Example 17.11**

*Problem*

A 100-mL sample of slurry from a solids contact unit is placed in a graduated cylinder and allowed to settle for 10 minutes. The settled biosolids at the bottom of the graduated cylinder after 10 minutes is 22 mL. What is the percent of settled biosolids of the sample?

*Solution*

Referring to Equation 17.9:

$$\% \text{ Settled biosolids} = \frac{22 \text{ mL}}{100 \text{ mL}} \times 100$$

$$= 22\%$$

**Example 17.12**

*Problem*

A 100-mL sample of slurry from a solids contact unit is placed in a graduated cylinder. After 10 minutes, a total of 21 mL of biosolids settled to the bottom of the cylinder. What is the percent settled biosolids of the sample?

*Solution*

Referring to Equation 17.9:

$$\% \text{ Settled biosolids} = \frac{21 \text{ mL}}{100 \text{ mL}} \times 100$$

$$= 21\%$$

## DETERMINING LIME DOSAGE (mg/L)

During the alum dosage process, lime is sometimes added to provide adequate alkalinity ($HCO_3^-$) in the solids contact clarification process for the coagulation and precipitation of the solids. To determine the necessary lime dose (in mg/L), three steps are required.

First, the total alkalinity required is calculated. The total alkalinity required to react with the alum to be added and provide proper precipitation is determined using the following equation:

$$\text{Total alkalinity required (mg/L)} =$$

$$\underset{(1 \text{ mg/L alum reacts with } 0.45 \text{ mg/L alk.})}{\underset{\uparrow}{\text{Alkalinity reacting with alum (mg/L)}}} + \text{alkalinity in the water (mg/L)} \quad (17.10)$$

**Example 17.13**

*Problem*

Raw water requires an alum dose of 45 mg/L, as determined by jar testing. If a residual 30-mg/L alkalinity must be present in the water to ensure complete precipitation of alum added, what is the total alkalinity required (in mg/L)?

*Solution*

First, calculate the alkalinity that will react with 45-mg/L alum:

$$\frac{0.45 \text{ mg/L alk.}}{1 \text{ mg/L alum}} = \frac{x \text{ mg/L alk.}}{45 \text{ mg/L alum}}$$

$$x = 0.45 \times 45$$

$$= 20.25 \text{ mg/L alk.}$$

Next, calculate the total alkalinity required:

$$\text{Total alk. required (mg/L)} = \text{alk. to react with alum (mg/L)} + \text{residual alk. (mg/L)}$$

$$= 20.25 \text{ mg/L} + 30 \text{ mg/L}$$

$$= 50.25 \text{ mg/L}$$

**Example 17.14**

*Problem*

Jar tests indicate that 36-mg/L alum are optimum for a particular raw water. If a residual 30-mg/L alkalinity must be present to promote complete precipitation of the alum added, what is the total alkalinity required (in mg/L)?

*Solution*

First, calculate the alkalinity that will react with 36-mg/L alum:

$$\frac{0.45 \text{ mg/L alk.}}{1 \text{ mg/L alum}} = \frac{x \text{ mg/L alk.}}{36 \text{ mg/L alum}}$$

$$x = 0.45 \times 36$$

$$= 16.2$$

Then, calculate the total alkalinity required:

$$\text{Total alk. required (mg/L)} = 16.2 \text{ mg/L} + 30 \text{ mg/L}$$

$$= 46.2 \text{ mg/L}$$

In the next step, we make a comparison between required alkalinity and alkalinity already in the raw water to determine how many mg/L alkalinity should be added to the water. Equation 17.11 is used to make this calculation:

$$\text{Alk. to be added to the water } (\text{mg/L}) = \text{total alk. required } (\text{mg/L}) - \text{alk. present in the water } (\text{mg/L}) \tag{17.11}$$

**Example 17.15**

*Problem*

A total of 44-mg/L alkalinity is required to react with alum and ensure proper precipitation. If the raw water has an alkalinity of 30 mg/L as bicarbonate, how many mg/L alkalinity should be added to the water?

*Solution*

Referring to Equation 17.11:

$$\text{Alk. to be added (mg/L)} = 44 \text{ mg/L} - 30 \text{ mg/L}$$

$$= 14 \text{ mg/L}$$

Finally, after determining the amount of alkalinity to be added to the water, we determine how much lime (the source of alkalinity) must be added. We accomplish this by using the ratio shown in Example 17.16.

**Example 17.16**

*Problem*

It has been calculated that 16 mg/L alkalinity must be added to a raw water. How much mg/L lime will be required to provide this amount of alkalinity? (One mg/L alum reacts with 0.45 mg/L alk., and 1 mg/L alum reacts with 0.35 mg/L lime.)

*Solution*

First, determine the mg/L lime required by using a proportion that relates bicarbonate alkalinity to lime:

$$\frac{0.45 \text{ mg/L alk.}}{0.35 \text{ mg/L lime}} = \frac{16 \text{ mg/L alk.}}{x \text{ mg/L lime}}$$

Next, we cross-multiply:

$$0.45\ x = 16 \times 0.35$$

$$x = \frac{16 \times 0.35}{0.45}$$

$$= 12.4\ \text{mg/L lime}$$

In Example 17.17, we use all three steps to determine the lime dosage (mg/L) required.

**Example 17.17**

*Problem*

Given the following data, calculate the lime dose required (in mg/L):

Alum dose required (determined by jar tests) = 52 mg/L
Residual alkalinity required for precipitation = 30 mg/L
1 mg/L alum reacts with 0.35 mg/L lime
1 mg/L alum reacts with 0.45 mg/L alkalinity
Raw water alkalinity — 36 mg/L

*Solution*

To calculate the total alkalinity required, we must first calculate the alkalinity that will react with 52 mg/L alum:

$$\frac{0.45\ \text{mg/L alk.}}{1\ \text{mg/L alum}} = \frac{x\ \text{mg/L alk.}}{52\ \text{mg/L alum}}$$

$$x = 0.45 \times 52$$

$$= 23.4\ \text{mg/L alk.}$$

The total alkalinity requirement can now be determined:

Total alk. required (mg/L) = alk. to react with alum (mg/L) + residual alk. (mg/L)

= 23.4 mg/L + 30 mg/L

= 53.4 mg/L

Next, calculate how much alkalinity must be added to the water:

Alk. to be added (mg/L) = Total alk. required (mg/L) – alk. present (mg/L)

= 53.4 mg/L – 36 mg/L

= 17.4 mg/L

Finally, calculate the lime required to provide this additional alkalinity:

$$\frac{0.45 \text{ mg/L alk.}}{0.35 \text{ mg/L lime}} = \frac{17.4 \text{ mg/L alk.}}{x \text{ mg/L lime}}$$

$$0.4x = 17.4 \times 0.35$$

$$x = \frac{17.4 \times 0.35}{0.45}$$

$$= 13.5 \text{ mg/L lime}$$

## DETERMINING LIME DOSAGE (lb/day)

After the lime dose has been determined in terms of mg/L, it is a fairly simple matter to calculate the lime dose in lb/day, which is one of the most common calculations in water and wastewater treatment. To convert from mg/L to lb/day lime dose, we use the following equation:

$$\text{Lime (lb/day)} = \text{lime (mg/L)} \times \text{flow (MGD)} \times 8.34 \text{ lb/gal} \tag{17.12}$$

### Example 17.18

*Problem*

The lime dose for raw water has been calculated to be 15.2 mg/L. If the flow to be treated is 2.4 MGD, how many lb/day lime will be required?

*Solution*

$$\text{Lime (lb/day)} = \text{lime (mg/L)} \times \text{flow (MGD)} \times 8.34 \text{ lb/gal}$$

$$= 15.2 \text{ mg/L} \times 2.4 \text{ MGD} \times 8.34 \text{ lb/gal}$$

$$= 304 \text{ lb/day lime}$$

### Example 17.19

*Problem*

The flow to a solids contact clarifier is 2,650,000 gpd. If the lime dose required is determined to be 12.6 mg/L, how many lb/day lime will be required?

*Solution*

$$\text{Lime (lb/day)} = \text{Lime (mg/L)} \times \text{flow (MGD)} \times 8.34 \text{ lb/gal}$$

$$= 12.6 \text{ mg/L} \times 2.65 \text{ MGD} \times 8.34 \text{ lb/gal}$$

$$= 278 \text{ lb/day}$$

## DETERMINING LIME DOSAGE (g/min)

To convert from mg/L lime to grams/min (g/min) lime, use Equation 17.13:

✔ **Key Point:** 1 lb = 453.6 g.

$$\text{Lime}\left(\text{g/min}\right) = \frac{\text{lime}\left(\text{lb/day}\right) \times 453.6\left(\text{g/lb}\right)}{1440 \text{ min/day}} \tag{17.13}$$

### Example 17.20

*Problem*

A total of 275 lb/day lime will be required to raise the alkalinity of the water passing through a solids-contact clarification process. How many grams per minute lime does this represent?

*Solution*

Referring to Equation 17.13:

$$\text{Lime}\,(\text{g/min}) = \frac{275\ \text{lb/day} \times 453.6\ \text{g/lb}}{1440\ \text{min/day}}$$

$$= 86.6\ \text{g/min}$$

### Example 17.21

*Problem*

A lime dose of 150 lb/day is required for a solids-contact clarification process. How many grams per minute lime does this represent?

*Solution*

Referring to Equation 17.13:

$$\text{Lime}\,(\text{g/min}) = \frac{150\ \text{lb/day} \times 453.6\ \text{g/lb}}{1440\ \text{min/day}}$$

$$= 47.3\ \text{g/min}$$

# 18 Filtration Calculations

I was always aware, I think, of the water in the soil, the way it travels from particle to particle, molecules adhering, clustering, evaporating, heating, cooling, freezing, rising upward to the surface and fogging the cool air or sinking downward, dissolving the nutrient and that, quick in everything it does, endlessly working and flowing.

**J.A. Smiley**
***A Thousand Acres***

## TOPICS



## WATER FILTRATION

Water filtration is a physical process of separating suspended and colloidal particles from waste by passing the water through a granular material. The process of filtration involves straining, settling, and adsorption. As floc passes into the filter, the spaces between the filter grains become clogged, reducing this opening and increasing removal. Some material is removed merely because it settles on a media grain. One of the most important processes is adsorption of the floc onto the surface of individual filter grains. In addition to removing silt and sediment, flock, algae, insect larvae, and any other large elements, filtration also contributes to the removal of bacteria and protozoans such as *Giardia lamblia* and *Cryptosporidium*. Some filtration processes are also used for iron and manganese removal.

The *surface water treatment rule* (SWTR) specifies four filtration technologies, although SWTR also allows the use of alternate filtration technologies (e.g., cartridge filters). These include slow sand filtration (see Figure 18.1), rapid sand filtration, pressure filtration, diatomaceous earth filtration, and direct filtration. Of these, all but rapid sand filtration is commonly employed in small water systems that use filtration. Each type of filtration system has advantages and disadvantages. Regardless of the type of filter, however, filtration involves the processes of *straining* (where particles are captured in the small spaces between filter media grains), *sedimentation* (where the particles land on top of the grains and stay there), and *adsorption* (where a chemical attraction occurs between the particles and the surface of the media grains).

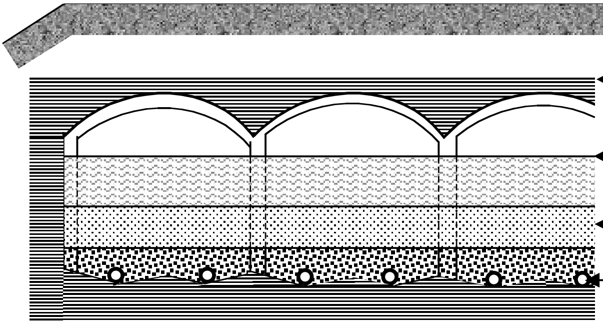


**FIGURE 18.1** Slow sand filter.

## FLOW RATE THROUGH A FILTER (gpm)

Flow rate in gpm through a filter can be determined by simply converting the gpd flow rate indicated on the flow meter. The flow rate (gpm) can be calculated by taking the meter flow rate (gpd) and dividing by 1440 min/day, as shown in Equation 18.1.

$$\text{Flow rate (gpm)} = \frac{\text{flow rate (gpd)}}{1440 \text{ min/day}} \tag{18.1}$$

### Example 18.1

*Problem*

The flow rate through a filter is 4.25 MGD. What is this flow rate expressed as gpm?

*Solution*

Referring to Equation 18.1:

$$\text{Flow rate (gpm)} = \frac{4.25 \text{ MGD}}{1440 \text{ min/day}}$$

$$= \frac{4,250,000 \text{ gpd}}{1440 \text{ min/day}}$$

$$= 2951 \text{ gpm}$$

### Example 18.2

*Problem*

During a 70-hour filter run, 22.4 million gallons of water are filtered. What is the average flow rate through the filter (in gpm) during this filter run?

*Solution*

$$\text{Flow rate (gpm)} = \frac{\text{total gallons produced}}{\text{filter run (min)}}$$

$$= \frac{22,400,000 \text{ gal}}{70 \text{ hr} \times 60 \text{ min/hr}}$$

$$= 5333 \text{ gpm}$$

### Example 18.3

*Problem*

At an average flow rate of 4000 gpm, how long a filter run (in hours) would be required to produce 25 MG of filtered water?

*Solution*

Write the equation as usual, filling in known data:

$$\text{Flow rate (gpm)} = \frac{\text{total gallons produced}}{\text{filter run (min)}}$$

$$4000 \text{ gpm} = \frac{25,000,000 \text{ gal}}{x \text{ hr} \times 60 \text{ min/hr}}$$

Then solve for *x:*

$$x = \frac{25,000,000 \text{ gal}}{4000 \times 60}$$

$$= 104 \text{ hr}$$

### Example 18.4

*Problem*

A filter box is 20 ft by 30 ft (including the sand area). If the influent valve is shut, the water drops 3 inches per minute. What is the rate of filtration in MGD?

*Solution*

$$\text{Filter box} = 20 \text{ ft} \times 30 \text{ ft}$$

$$\text{Water drops} = 3.0 \text{ in./min}$$

Find the volume of water passing through the filter

$$\text{Volume} = \text{area} \times \text{height}$$

$$\text{Area} = \text{width} \times \text{length}$$

✔ **Note:** The best way to perform calculations for this type of problem is step by step, breaking down the problem into what is given and what is to be found.

- *Step 1: Calculate area.*

$$\text{Area} = 20 \text{ ft} \times 30 \text{ ft} = 600 \text{ ft}^2$$

Then convert 3 in. into feet:

$$3/12 = 0.25 \text{ ft}$$

$$\text{Volume} = 600 \text{ ft}^2 \times 0.25 \text{ ft}$$

$$= 150 \text{ ft}^3 \text{ of water passing through the filter in one minute}$$

- *Step 2:* Convert cubic feet to gallons.

$$150 \text{ ft}^3 \times 7.48 \text{ gal/ft}^3 = 1122 \text{ gal/min}$$

- *Step 3:* The problem asks for the rate of filtration in MGD. To find MGD, multiply the number of gallons per minute by the number of minutes per day.

$$1122 \text{ gal/min} \times 1440 \text{ min/day} = 1.62 \text{ MGD}$$

### Example 18.5

*Problem*

The influent valve to a filter is closed for 5 minutes. During this time, the water level in the filter drops 0.8 ft (9.6 inches). If the filter is 45 ft long and 15 ft wide, what is the gpm flow rate through the filter? (Water drop equals 0.16 ft/min.)

*Solution*

First calculate ft$^3$/min (cfm) flow rate using the $Q = A \times V$ equation:

$$\begin{aligned} Q \text{ (cfm)} &= \text{length (ft)} \times \text{width (ft)} \times \text{drop velocity (ft/min)} \\ &= 45 \text{ ft} \times 15 \text{ ft} \times 0.16 \text{ ft/min} \\ &= 108 \text{ cfm} \end{aligned}$$

Then convert the cfm flow rate to a gpm flow rate:

$$108 \text{ cfm} \times 7.48 \text{ gal/cu ft} = 808 \text{ gpm}$$

## FILTRATION RATE

One measure of filter production is filtration rate (generally range from 2 to 10 gpm/sq ft), which is the gallons per minute of water filtered through each square foot of filter area. Along with filter run time, it provides valuable information for the operation of filters. Filtration rate is determined using Equation 18.2.

$$\text{Filtration rate (gpm/sq ft)} = \frac{\text{flow rate (gpm)}}{\text{filter surface area (sq ft)}} \tag{18.2}$$

### Example 18.6

*Problem*

A filter 18 ft by 22 ft receives a flow of 1750 gpm. What is the filtration rate in gpm/sq ft?

*Solution*

Referring to Equation 18.2:

$$\begin{aligned} \text{Filtration rate} &= \frac{1750 \text{ gpm}}{18 \text{ ft} \times 22 \text{ ft}} \\ &= 4.4 \text{ gpm/sq ft} \end{aligned}$$

### Example 18.7

*Problem*

A filter 28 ft long and 18 ft wide treats a flow of 3.5 MGD. What is the filtration rate in gpm/sq ft?

*Solution*

$$\text{Flow rate} = \frac{3,500,000 \text{ gpd}}{1440 \text{ min/day}} = 2431 \text{ gpm}$$

$$\text{Filtration rate (gpm/sq ft)} = \frac{2431 \text{ gpm}}{28 \text{ ft} \times 18 \text{ ft}}$$

$$= 4.8 \text{ gpm/sq ft}$$

### Example 18.8

*Problem*

A filter 45 ft long and 20 ft wide produces a total of 18 MG during a 76-hour filter run. What is the average filtration rate for this filter run (in gpm/sq ft)?

*Solution*

First calculate the gpm flow rate through the filter:

$$\text{Flow rate (gpm)} = \frac{\text{total gallons produced}}{\text{filter run (min)}}$$

$$= \frac{18,000,000 \text{ gal}}{76 \text{ hr} \times 60 \text{ min/hr}}$$

$$= 3947 \text{ gpm}$$

Then calculate filtration rate:

$$\text{Filtration rate} = \frac{\text{flow rate (gpm)}}{\text{filter area (sq ft)}}$$

$$= \frac{3947 \text{ gpm}}{45 \text{ ft} \times 20 \text{ ft}}$$

$$= 4.4 \text{ gpm/sq ft}$$

### Example 18.9

*Problem*

A filter is 40 ft long and 20 ft wide. During a test of flow rate, the influent valve to the filter is closed for 6 minutes. The water level drop during this period is 16 inches. What is the filtration rate for the filter (in gpm/sq ft)?

*Solution*

First calculate gpm flow rate, using the $Q = A \times V$ equation:

$$Q\,(\text{gpm}) = \text{length (ft)} \times \text{width (ft)} \times \text{drop velocity (ft/min)} \times 7.48 \text{ gal/cu ft}$$

$$= \frac{40 \text{ ft} \times 20 \text{ ft} \times 1.33 \text{ ft} \times 7.48 \text{ gal/cu ft}}{6 \text{ min}}$$

$$= 1326 \text{ gpm}$$

Then calculate filtration rate:

$$\text{Filtration rate} = \frac{\text{flow rate (gpm)}}{\text{filter area (sq ft)}}$$

$$= \frac{1326 \text{ gpm}}{40 \text{ ft} \times 20 \text{ ft}}$$

$$= 1.6 \text{ gpm/sq ft}$$

## UNIT FILTER RUN VOLUME (UFRV)

The unit filter run volume (UFRV) calculation indicates the total gallons passing through each square foot of filter surface area during an entire filter run. This calculation is used to compare and evaluate filter runs. UFRVs are usually at least 5000 gal/sq ft and generally in the range of 10,000 gpd/sq ft. The UFRV value will begin to decline as the performance of the filter begins to deteriorate. The equation to be used in these calculations is shown below:

$$\text{UFRV} = \frac{\text{total gallons filtered}}{\text{filter surface area (sq ft)}} \tag{18.3}$$

**Example 18.10**

*Problem*

The total water filtered during a filter run (between backwashes) is 2,220,000 gal. If the filter is 18 ft by 18 ft, what is the UFRV (in gal/sq ft)?

*Solution*

Referring to Equation 18.3:

$$\text{UFRV} = \frac{2,220,000 \text{ gal}}{18 \text{ ft} \times 18 \text{ ft}}$$

$$= 6852 \text{ gal/sq ft}$$

**Example 18.11**

*Problem*

The total water filtered during a filter run is 4,850,000 gallons. If the filter is 28 ft by 18 ft, what is the unit filter run volume (in gal/sq ft)?

*Solution*

Referring again to Equation 18.3:

$$\text{UFRV} = \frac{4{,}850{,}000 \text{ gal}}{28 \text{ ft} \times 18 \text{ ft}}$$

$$= 9623 \text{ gal/sq ft}$$

Equation 18.3 can be modified as shown in Equation 18.4 to calculate the unit filter run volume given the filtration rate and filter run data.

$$\text{UFRV} = \text{Filtration rate (gpm/sq ft)} \times \text{filter run time (min)} \tag{18.4}$$

**Example 18.12**

*Problem*

The average filtration rate for a filter was determined to be 2.0 gpm/sq ft. If the filter run time was 4250 minutes, what was the unit filter run volume (in gal/sq ft)?

*Solution*

Referring to Equation 18.4:

$$\text{UFRV} = 2.0 \text{ gpm/sq ft} \times 4250 \text{ min}$$

$$= 8500 \text{ gal/sq ft}$$

The problem indicates that, at an average filtration rate of 2.0 gallons entering each square foot of filter each minute, the total number of gallons entering during the total filter run is 4250 times that amount.

**Example 18.13**

*Problem*

The average filtration rate during a particular filter run was determined to be 3.2 gpm/sq ft. If the filter run time was 61.0 hours, what was the UFRV for the filter run (in gal/ft$^2$)?

*Solution*

$$\text{UFRV} = \text{filtration rate (gpm/sq ft)} \times \text{filter run (hr)} \times 60 \text{ min/hr}$$

$$= 3.2 \text{ gpm/sq ft} \times 61.0 \text{ hr} \times 60 \text{ min/hr}$$

$$= 11{,}712 \text{ gal/sq ft}$$

## BACKWASH RATE

In filter backwashing, one of the most important operational parameters to be determined is the amount of water (in gallons) required for each backwash. This amount depends on the design of the filter and the quality of the water being filtered. The actual washing typically lasts 5 to 10 minutes and uses amounts to 1 to 5% of the flow produced.

### Example 18.14

*Problem*

A filter has the following dimensions:

Length = 30 ft
Width = 20 ft
Depth of filter media = 24 inches

Assuming a backwash rate of 15 gallons per square foot per minute is recommended, and a 10-minutes backwash is required, calculate the amount of water in gallons required for each backwash.

*Solution*

Step 1: Area of filter = 30 ft × 20 ft = 600 $ft^2$
Step 2: Gallons of water used per square foot of filter = 15 $gal/ft^2/min$ × 10 min = 150 $gal/ft^2$
Step 3: Gallons required for backwash = 150 $gal/ft^2$ × 600 $ft^2$ = 90,000 gal

Typically, backwash rates will range from 10 to 25 gpm/sq ft. The backwash rate is determined by:

$$\text{Backwash} = \frac{\text{flow rate (gpm)}}{\text{filter area (sq ft)}} \tag{18.5}$$

### Example 18.15

*Problem*

A filter that is 30 ft by 10 ft has a backwash rate of 3120 gpm. What is the backwash rate (in gpm/sq ft)?

*Solution*

Referring to Equation 18.5:

$$\text{Backwash rate (gpm/sq ft)} = \frac{3120 \text{ gpm}}{30 \text{ ft} \times 10 \text{ ft}}$$

$$= 10.4 \text{ gpm/sq ft}$$

### Example 18.16

*Problem*

A filter that is 20 ft long and 20 ft wide has a backwash flow rate of 4.85 MGD. What is the filter backwash rate (in gpm/sq ft)?

*Solution*

Again referring to Equation 18.5:

$$\text{Flow rate (gpm)} = \frac{4{,}850{,}000 \text{ gpd}}{1440 \text{ min/day}}$$

$$= 3368 \text{ gpm}$$

$$\text{Backwash rate (gpm/sq ft)} = \frac{3368 \text{ gpm}}{20 \text{ ft} \times 20 \text{ ft}}$$

$$= 8.42 \text{ gpm/sq ft}$$

### Backwash Rise Rate

Backwash rate is occasionally measured as the upward velocity of the water during backwashing expressed as inches/minute rise. To convert from a gpm/sq ft backwash rate to an in./min rise rate, use either Equation 18.6 or Equation 18.7:

$$\text{Backwash rate (in./min)} = \frac{\text{backwash rate (gpm/sq ft)} \times 12 \text{ in./ft}}{7.48 \text{ gal/cu ft}} \tag{18.6}$$

$$\text{Backwash rate (in./min)} = \text{backwash rate (gpm/sq ft)} \times 1.6 \tag{18.7}$$

**Example 18.17**

*Problem*

A filter has a backwash rate of 16 gpm/sq ft. What is this backwash rate expressed as an in./min rise rate?

*Solution*

Referring to Equation 18.6:

$$\text{Backwash rate (in./min)} = \frac{\text{backwash rate (gpm/sq ft)} \times 12 \text{ in./ft}}{7.48 \text{ gal/sq ft}}$$

$$= \frac{16 \text{ gpm/sq ft} \times 12 \text{ in./ft}}{7.48 \text{ gal/cu ft}}$$

$$= 25.7 \text{ in./min}$$

**Example 18.18**

*Problem*

A filter that is 22 ft long and 12 ft wide has a backwash rate of 3260 gpm. What is this backwash rate expressed as an in./min rise?

*Solution*

First calculate the backwash rate as gpm/sq ft:

$$\text{Backwash rate (gpm/sq ft)} = \frac{\text{flow rate (gpm)}}{\text{filter area (sq ft)}}$$

$$= \frac{3260 \text{ gpm}}{22 \text{ ft} \times 12 \text{ ft}}$$

$$= 12.3 \text{ gpm/sq ft}$$

Then convert gpm/ft$^2$ to an in./min rise rate:

$$\text{Rise rate (in./min)} = \frac{12.3 \text{ gpm/ft}^2 \times 12 \text{ in./ft}}{7.48 \text{ gal/cu ft}}$$

$$= 19.7 \text{ in./min}$$

## VOLUME OF BACKWASH WATER REQUIRED (gal)

To determine the volume of water required for backwashing, we must know both the desired backwash flow rate (gpm) and the duration of backwash (min):

$$\text{Backwash water volume (gal)} = \text{Backwash (gpm)} \times \text{duration of backwash (min)} \quad (18.8)$$

**Example 18.19**

*Problem*

For a backwash flow rate of 9000 gpm and a total backwash time of 8 minutes, how many gallons of water will be required for backwashing?

*Solution*

Referring to Equation 18.8:

$$\text{Backwash water volume (gal)} = 9000 \text{ gpm} \times 8 \text{ min}$$

$$= 72{,}000 \text{ gal}$$

**Example 18.20**

*Problem*

How many gallons of water would be required to provide a backwash flow rate of 4850 gpm for a total of 5 minutes?

*Solution*

Again referring to Equation 18.8:

$$\text{Backwash water volume (gal)} = 4{,}850 \text{ gpm} \times 7 \text{ min}$$

$$= 33{,}950 \text{ gal}$$

## REQUIRED DEPTH OF BACKWASH WATER TANK (ft)

The required depth of water in the backwash water tank is determined from the volume of water required for backwashing:

$$\text{Volume (gal)} = 0.785 \times D^2 \times \text{depth (ft)} \times 7.48 \text{ gal/cu ft} \quad (18.9)$$

**Example 18.21**

*Problem*

The volume of water required for backwashing has been calculated to be 85,000 gallons. What is the required depth of water in the backwash water tank to provide this amount of water if the diameter of the tank is 60 ft?

*Solution*

Use the volume equation for a cylindrical tank, fill in known data, then solve for $x$. Referring to Equation 18.9:

$$85,000 \text{ gal} = 0.785 \times 60 \text{ ft} \times 60 \text{ ft} \times x \text{ ft} \times 7.48 \text{ gal/cu ft}$$

$$x = \frac{65,000}{0.785 \times 60 \times 60 \times 7.48}$$

$$x = 4 \text{ ft}$$

**Example 18.22**

*Problem*

A total of 66,000 gallons of water will be required for backwashing a filter at a rate of 8000 gpm for a 9-minute period. What depth of water is required if the backwash tank has a diameter of 50 ft?

*Solution*

Using Equation 18.9:

$$66,000 \text{ gal} = 0.785 \times 50 \text{ ft} \times 50 \text{ ft} \times x \text{ ft} \times 7.48 \text{ gal/cu ft}$$

$$x = \frac{66,000}{0.785 \times 50 \times 50 \times 7.48}$$

$$x = 4.5 \text{ ft}$$

## BACKWASH PUMPING RATE (gpm)

The desired backwash-pumping rate (gpm) for a filter depends on the desired backwash rate (gpm/sq ft) and area of the filter (sq ft). The backwash pumping rate (gpm) can be determined by:

$$\text{Backwash pumping rate (gpm)} = \text{Desired backwash rate (gpm/sq ft)} \times \text{filter area (sq ft)} \quad (18.10)$$

**Example 18.23**

*Problem*

A filter is 25 ft long and 20 ft wide. If the desired backwash rate is 22 gpm/sq ft, what backwash pumping rate will be required (in gpm)?

*Solution*

The desired backwash flow through each square foot of filter area is 20 gpm. The total gpm flow through the filter is therefore 20 gpm times the entire square foot area of the filter. Referring to Equation 18.10:

$$\text{Backwash pumping rate (gpm)} = 20 \text{ gpm/sq ft} \times 25 \text{ ft} \times 20 \text{ ft}$$

$$= 10,000 \text{ gpm}$$

**Example 18.24**

*Problem*

The desired backwash-pumping rate for a filter is 12 gpm/sq ft. If the filter is 20 ft long and 20 ft wide, what backwash pumping rate will be required (in gpm)?

*Solution*

Again referring to Equation 18.10:

$$\text{Backwash pumping rate (gpm)} = 12 \text{ gpm/sq ft} \times 20 \text{ ft} \times 20 \text{ ft}$$

$$= 4800 \text{ gpm}$$

## PERCENT PRODUCT WATER USED FOR BACKWATERING

Along with measuring filtration rate and filter run time, another aspect of filter operation that is monitored for filter performance is the percent of product water used for backwashing. The equation for percent of product water used for backwashing calculations used is shown below:

$$\text{Backwash water } (\%) = \frac{\text{backwash water (gal)}}{\text{filtered water (gal)}} \times 100 \tag{18.11}$$

**Example 18.25**

*Problem*

During a filter run, 18,100,000 gallons of water were filtered. If 74,000 gallons of this product water were used for backwashing, what percent of the product water was used for backwashing?

*Solution*

Referring to Equation 18.11:

$$\text{Backwash water } (\%) = \frac{74{,}000 \text{ gal}}{18{,}100{,}000 \text{ gal}} \times 100$$

$$= 0.41\%$$

**Example 18.26**

*Problem*

A total of 11,400,000 gallons of water are filtered during a filter run. If 48,500 gallons of product water are used for backwashing, what percent of the product water is used for backwashing?

*Solution*

Again referring to Equation 18.11:

$$\text{Backwash water } (\%) = \frac{48{,}500 \text{ gal}}{11{,}400{,}000 \text{ gal}} \times 100$$

$$= 0.43\%$$

## PERCENT MUD BALL VOLUME

Mud balls are heavier deposits of solids near the top surface of the medium that break into pieces during backwash, resulting in spherical accretions (usually less than 12 inches in diameter) of floc and sand. The presence of mud balls in the filter media is checked periodically. The principal

objection to mud balls is that they diminish the effective filter area. To calculate the percent mud ball volume, we use the following:

$$\% \text{ Mud ball volume} = \frac{\text{mud ball volume (mL)}}{\text{total sample volume (mL)}} \times 100 \tag{18.12}$$

**Example 18.27**

*Problem*

A 3350-mL sample of filter media was taken for mud ball evaluation. The volume of water in the graduated cylinder rose from 500 mL to 525 mL when mud balls were placed in the cylinder. What is the percent mud ball volume of the sample?

*Solution*

First, determine the volume of mud balls in the sample:

$$525 \text{ mL} - 500 \text{ mL} = 25 \text{ mL}$$

Then calculate the percent mud ball volume using Equation 18.12:

$$\% \text{ Mud ball volume} = \frac{25 \text{ mL}}{3550 \text{ mL}} \times 100$$

$$= 0.75\%$$

**Example 18.28**

*Problem*

A filter is tested for the presence of mud balls. The mud ball sample has a total sample volume of 680 mL. Five samples were taken from the filter. When the mud balls were placed in 500 mL of water, the water level rose to 565 mL. What is the percent mud ball volume of the sample?

*Solution*

The mud ball volume is the volume the water rose:

$$565 \text{ mL} - 500 \text{ mL} = 65 \text{ mL}$$

Because five samples of media were taken, the total sample volume is five times the sample volume:

$$5 \times 680 \text{ mL} = 3400 \text{ mL}$$

Again referring to Equation 18.12:

$$\% \text{ Mud ball volume} = \frac{65 \text{ mL}}{3400 \text{ mL}} \times 100$$

$$= 1.9\%$$

# 19 Water Chlorination Calculations

Chlorine is the most commonly used substance for disinfection of water in the U.S. The addition of chlorine or chlorine compounds to water is referred to as *chlorination*. Chlorination is considered to be the single most important process for preventing the spread of waterborne disease.

## TOPICS



## CHLORINE DISINFECTION

Chlorine deactivates microorganisms through several mechanisms that can destroy most biological contaminants, including:

- Damaging the cell wall
- Altering the permeability of the cell (the ability to pass water in and out through the cell wall)
- Altering the cell protoplasm
- Inhibiting the enzyme activity of the cell so it is unable to use its food to produce energy
- Inhibiting cell reproduction

Chlorine is available in a number of different forms: (1) as pure elemental gaseous chlorine (a greenish-yellow gas possessing a pungent and irritating odor that is heavier than air, nonflammable, and nonexplosive), which, when released to the atmosphere, is toxic and corrosive; (2) as solid calcium hypochlorite (in tablets or granules); or (3) as a liquid sodium hypochlorite solution (in various strengths). The strength of one form of chlorine compared to the others that must be used for a given water system depends on the amount of water to be treated, configuration of the water system, local availability of the chemicals, and skill of the operator.

One of the major advantages of using chlorine is the effective residual that it produces. A residual indicates that disinfection is completed, and the system has an acceptable bacteriological quality. Maintaining a residual in the distribution system helps to prevent regrowth of those microorganisms that were injured but not killed during the initial disinfection stage.

## DETERMINING CHLORINE DOSAGE (FEED RATE)

The units of milligrams per liter (mg/L) and pounds per day (lb/day) are most often used to describe the amount of chlorine added or required. Equation 19.1 can be used to calculate either mg/L or lb/d chlorine dosage:

$$\text{Chlorine feed rate (lb/day)} = \text{chlorine (mg/L)} \times \text{flow (MGD)} \times 8.34\ \text{lb/gal} \tag{19.1}$$

### Example 19.1

*Problem*

Determine the chlorinator setting (lb/day) required to treat a flow of 4 MGD with a chlorine dose of 5 mg/L.

*Solution*

Referring to Equation 19.1:

$$\begin{aligned}\text{Chlorine (lb/day)} &= 5\ \text{mg/L} \times 4\ \text{MGD} \times 8.34\ \text{lb/gal}\\ &= 167\ \text{lb/day}\end{aligned}$$

### Example 19.2

*Problem*

A pipeline that is 12 inches in diameter and 1400 ft long is to be treated with a chlorine dose of 48 mg/L. How many lb of chlorine will this require?

*Solution*

Determine the gallon volume of the pipeline:

$$\begin{aligned}\text{Volume}\left(\text{gal}\right) &= 0.785 \times D^2 \times \text{length}\left(\text{ft}\right) \times 7.48\ \text{gal/cu ft}\\ &= 0.785 \times 1\ \text{ft} \times 1\ \text{ft} \times 1400\ \text{ft} \times 7.48\ \text{gal/cu ft}\\ &= 8221\ \text{gal}\end{aligned}$$

Now calculate the amount of chlorine required using Equation 19.1:

$$\begin{aligned}\text{Chlorine (lb)} &= 48\ \text{mg/L} \times 0.008221\ \text{MG} \times 8.34\ \text{lb/gal}\\ &= 3.3\ \text{lb}\end{aligned}$$

### Example 19.3

*Problem*

A chlorinator setting is 30 lb per 24 hr. If the flow being chlorinated is 1.25 MGD, what is the chlorine dosage (expressed as mg/L)?

*Solution*

Referring to Equation 19.1:

$$30\ \text{lb/day} = x\ \text{mg/L} \times 1.25\ \left(\text{MGD}\right) \times 8.34\ \text{lb/gal}$$

$$x = \frac{30}{1.25 \times 8.34}$$

$$x = 2.9\ \text{mg/L}$$

### Example 19.4

*Problem*

A flow of 1600 gpm is to be chlorinated. At a chlorinator setting of 48 lb per 24 hr, what would be the chlorine dosage (in mg/L)?

*Solution*

Convert the gpm flow rate to MGD flow rate:

$$1600 \text{ gpm} \times 1440 \text{ min/day} = 2{,}304{,}000 \text{ gpd}$$

$$= 2.304 \text{ MGD}$$

Now calculate the chlorine dosage in mg/L using Equation 19.1:

$$\text{Chlorine (lb/day)} = x \text{ mg/L} \times 2.304 \text{ MGD} \times 8.34 \text{ lb/gal} = 48 \text{ lb/day}$$

$$x = \frac{48}{2.304 \times 8.34}$$

$$= 2.5 \text{ mg/L}$$

## CALCULATING CHLORINE DOSE, DEMAND AND RESIDUAL

Common terms used in chlorination include the following:

- *Chlorine dose* — amount of chlorine added to the system. It can be determined by adding the desired residual for the finished water to the chlorine demand of the untreated water. Dosage can be either milligrams per liter (mg/L) or pounds per day (lb/day) (the most common being mg/L).

$$\text{Chlorine dose (mg/L)} = \text{chlorine demand (mg/L)} + \text{chlorine residual (mg/L)} \qquad (19.2)$$

- *Chlorine demand* — amount of chlorine used by iron, manganese, turbidity, algae, and microorganisms in the water. Because the reaction between chlorine and microorganisms is not instantaneous, demand is relative to time. For instance, the demand 5 minutes after applying chlorine will be less than the demand after 20 minutes. Demand, like dosage, is expressed in mg/L. The chlorine demand is as follows:

$$\text{Chlorine demand} = \text{chlorine dose} - \text{chlorine residual}$$

- *Chlorine residual* — amount of chlorine (determined by testing) remaining after the demand is satisfied. Residual, like demand, is based on time. The longer the time after dosage, the lower the residual will be, until all of the demand has been satisfied. Residual, like dosage and demand, is expressed in mg/L. The presence of a *free residual* of at least 0.2 to 0.4 ppm usually provides a high degree of assurance that the disinfection of the water is complete. *Combined residual* is the result of combining free chlorine with nitrogen compounds. Combined residuals are also referred to as chloramines. *Total chlorine residual* is the mathematical combination of free and combined residuals. Total residual can be determined directly with standard chlorine residual test kits.

The following examples illustrate the calculation of chlorine dose, demand, and residual using Equation 19.2.

### Example 19.5

*Problem*

A water sample is tested and found to have a chlorine demand of 1.7 mg/L. If the desired chlorine residual is 0.9 mg/L, what is the desired chlorine dose (in mg/L)?

*Solution*

Referring to Equation 19.2:

$$\text{Chlorine dose (mg/L)} = 1.7 \text{ mg/L} + 0.9 \text{ mg/L}$$

$$= 2.6 \text{ mg/L}$$

### Example 19.6

*Problem*

The chlorine dosage for water is 2.7 mg/L. If the chlorine residual after a 30-minute contact time is found to be 0.7 mg/L, what is the chlorine demand (in mg/L)?

*Solution*

Again referring to Equation 19.2:

$$\text{Chlorine dose (mg/L)} = 2.7 \text{ mg/L} = x \text{ mg/L} + 0.7 \text{ mg/L}$$

$$2.7 \text{ mg/L} - 0.7 \text{ mg/L} = x \text{ mg/L}$$

$$x \text{ chlorine demand} = 2.0 \text{ mg/L}$$

### Example 19.7

*Problem*

What should the chlorinator setting be (pounds per day) to treat a flow of 2.35 MGD if the chlorine demand is 3.2 mg/L and a chlorine residual of 0.9 mg/L is desired?

*Solution*

Determine the chlorine dosage (in mg/L):

$$\text{Chlorine dose (mg/L)} = 3.2 \text{ mg/L} + 0.9 \text{ mg/L}$$

$$= 4.1 \text{ mg/L}$$

Calculate the chlorine dosage (feed rate) in lb/d using Equation 19.1:

$$\text{Chlorine (lb/d)} = 4.1 \text{ mg/L} \times 2.35 \text{ MGD} \times 8.34 \text{ lb/gal}$$

$$= 80.4 \text{ lb/day}$$

## BREAKPOINT CHLORINATION CALCULATIONS

To produce a free chlorine residual, enough chlorine must be added to the water to produce what is referred to as *breakpoint chlorination* (i.e., the point at which near complete oxidation of nitrogen compounds is reached; any residual beyond breakpoint is mostly free chlorine) (see Figure 19.1). When chlorine is added to natural waters, the chlorine begins combining with and oxidizing the chemicals in the water before it begins disinfecting. Although residual chlorine will be detectable in the water, the chlorine will be in the combined form with a weak disinfecting power. As we see in Figure 19.1, adding more chlorine to the water at this point actually decreases the chlorine

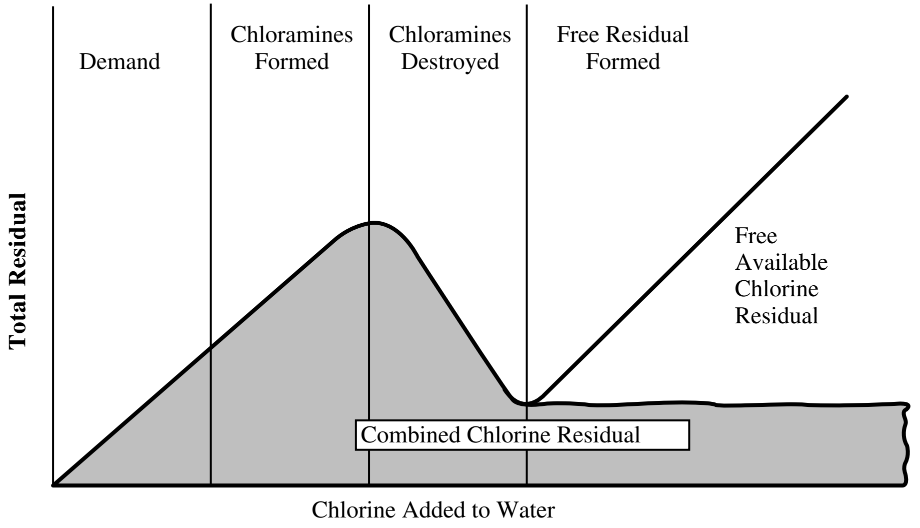


**FIGURE 19.1** Breakpoint chlorination curve.

residual as the additional chlorine destroys the combined chlorine compounds. At this stage, water may have a strong swimming pool or medicinal taste and odor. To avoid this taste and odor, add still more chlorine to produce a free residual chlorine. Free chlorine has the highest disinfecting power. The point at which most of the combined chlorine compounds have been destroyed and the free chlorine starts to form is the *breakpoint*.

✓ **Key Point:** The actual chlorine breakpoint of water can only be determined by experimentation.

To calculate the actual increase in chlorine residual that would result from an increase in chlorine dose, we use the mg/L-to-lb/day equation shown in Equation 19.3.

$$\text{Increase in chlorine dose (lb/day)} = \text{expected increase (mg/L)} \times \text{flow (MGD)} \times 8.34 \text{ lb/gal} \quad (19.3)$$

✓ **Key Point:** The actual increase in residual is simply a comparison of new and old residual data.

### Example 19.8

*Problem*

A chlorinator setting is increased by 2 lb/day. The chlorine residual before the increased dosage was 0.2 mg/L. After the increased chlorine dose, the chlorine residual was 0.5 mg/L. The average flow rate being chlorinated is 1.25 MGD. Is the water being chlorinated beyond the breakpoint?

*Solution*

Calculate the expected increase in chlorine residual. Use Equation 19.3:

$$2 \text{ lb/day} = x \text{ mg/L} \times 1.25 \text{ MGD} \times 8.34 \text{ lb/gal}$$

$$x = \frac{2}{1.25 \times 8.34}$$

$$= 0.19 \text{ mg/L}$$

Actual increase in residual is:

$$0.5 \text{ mg/L} - 0.19 \text{ mg/L} = 0.31 \text{ mg/L}$$

**Example 19.9**

*Problem*

A chlorinator setting of 18 lb chlorine per 24 hours results in a chlorine residual of 0.3 mg/L. The chlorinator setting is increased to 22 lb per 24 hours. The chlorine residual increased to 0.4 mg/L at this new dosage rate. The average flow being treated is 1.4 MGD. On the basis of these data, is the water being chlorinated past the breakpoint?

*Solution*

Calculate the expected increase in chlorine residual using Equation 19.3:

$$4 \text{ lb/day} = x \text{ mg/L} \times 1.4 \text{ MGD} \times 8.34 \text{ lb/gal}$$

$$x = \frac{4}{1.4 \times 8.34}$$

$$= 0.34 \text{ mg/L}$$

Actual increase in residual:

$$0.4 \text{ mg/L} - 0.3 \text{ mg/L} = 0.1 \text{ mg/L}$$

## CALCULATING DRY HYPOCHLORITE FEED RATE

The most commonly used dry hypochlorite, calcium hypochlorite, contains about 65 to 70% available chlorine, depending on the brand. Because hypochlorites are not 100% pure chorine, more lb/d must be fed into the system to obtain the same amount of chlorine for disinfection. The equation used to calculate the lb/d hypochlorite required by can be found by:

$$\text{Hypochlorite (lb/day)} = \frac{\text{chlorine (lb/day)}}{\dfrac{\text{\% available chlorine}}{100}} \tag{19.4}$$

**Example 19.10**

*Problem*

A chlorine dosage of 110 lb/day is required to disinfect a flow of 1,550,000 gpd. If the calcium hypochlorite to be used contains 65% available chlorine, how many pounds per day hypochlorite will be required for disinfection?

*Solution*

Because only 65% of the hypochlorite is chlorine, more than 110 lb of hypochlorite will be required. Using Equation 19.4:

$$\text{Hypochlorite (lb/day)} = \frac{110 \text{ lb/day}}{\dfrac{65}{100}}$$

$$= \frac{100}{0.65}$$

$$= 169 \text{ lb/day}$$

### Example 19.11

*Problem*

A water flow of 900,000 gpd requires a chlorine dose of 3.1 mg/L. If calcium hypochlorite (65% available chlorine) is to be used, how many lb/day of hypochlorite are required?

*Solution*

Calculate the necessary lb/day chlorine feed rate using Equation 19.1:

$$\text{Chlorine (lb/day)} = 3.1\ \text{mg/L} \times 0.90\ \text{MGD} \times 8.34\ \text{lb/gal}$$

$$= 23\ \text{lb/day}$$

Calculate the lb/day hypochlorite using Equation 19.4:

$$\text{Hypochlorite}\left(\text{lb/day}\right) = \frac{23\ \text{lb/day chlorine}}{0.65\ \text{available chlorine}}$$

$$= 35\ \text{lb/day}$$

### Example 19.12

*Problem*

A tank contains 550,000 gallons of water and is to receive a chlorine dose of 2.0 mg/L. How many pounds of calcium hypochlorite (65% available chlorine) will be required?

*Solution*

$$\text{Hypochlorite (lb)} = \frac{\text{chlorine}\left(\text{mg/L}\right) \times \text{volume (MG)} \times 8.34\ \text{lb/gal}}{\dfrac{\%\ \text{available chlorine}}{100}}$$

$$= \frac{2.0\ \text{mg/L} \times 0.550\ \text{MG} \times 8.34\ \text{lb/gal}}{\dfrac{65}{100}}$$

$$= \frac{9.2\ \text{lb}}{0.65}$$

$$= 14.2\ \text{lb}$$

### Example 19.13

*Problem*

A total of 40 lb of calcium hypochlorite (65% available chlorine) is used in a day. If the flow rate treated is 1,100,000 gpd, what is the chlorine dosage (in mg/L)?

*Solution*

Calculate the lb/day chlorine dosage:

$$40\ \text{lb/day hypochlorite} = \frac{x\ \text{lb/day chlorine}}{0.65}$$

$$x = 0.65 \times 40$$

$$x = 26\ \text{lb/day chlorine}$$

Then calculate mg/L chlorine, using Equation 19.3 and filling in the known information:

$$26 \text{ lb/day chlorine} = x \text{ mg/L chlorine} \times 1.10 \text{ MGD} \times 8.34 \text{ lb/gal}$$

$$x = \frac{26 \text{ lb/day}}{1.10 \text{ MGD} \times 8.34 \text{ lb/gal}}$$

$$x = 2.8 \text{ mg/L chlorine}$$

**Example 19.14**

*Problem*

A flow of 2,550,000 gpd is disinfected with calcium hypochlorite (65% available chlorine). If 50 lb of hypochlorite are used in a 24-hour period, what is the chlorine dosage (in mg/L)?

*Solution*

Calculate the chlorine dosage (lb/day):

$$50 \text{ lb/day Hypochlorite} = \frac{x \text{ lb/day chlorine}}{0.65}$$

$$x = 3.25 \text{ lb/day chlorine}$$

Calculate the mg/L chlorine:

$$x \text{ mg/L Chlorine} \times 2.55 \text{ MGD} \times 8.34 \text{ lb/gal} = 32.5 \text{ lb/day}$$

$$= 1.5 \text{ mg/L}$$

## CALCULATING HYPOCHLORITE SOLUTION FEED RATE

Liquid hypochlorite (i.e., sodium hypochlorite) is supplied as a clear, greenish-yellow liquid in strengths from 5.25 to 16% available chlorine. Often referred to as "bleach," it is, in fact, used for bleaching — common household bleach is a solution of sodium hypochlorite containing 5.25% available chlorine. When calculating gallons per day (gpd) liquid hypochlorite, the lb/d hypochlorite required must be convert to gpd hypochlorite. This conversion is accomplished using Equation 19.5.

$$\text{Hypochlorite (gpd)} = \frac{\text{hypochlorite (lb/day)}}{8.34 \text{ lb/gal}} \tag{19.5}$$

**Example 19.15**

*Problem*

A total of 50 lb/day sodium hypochlorite is required for disinfection of a flow of 1.5 MGD. How many gallons per day hypochlorite is this?

*Solution*

Because lb/day hypochlorite has already has been calculated, we simply convert lb/d to gpd:

$$\text{Hypochlorite (gpd)} = \frac{\text{hypochlorite (lb/day)}}{8.34 \text{ lb/gal}}$$

$$= \frac{50 \text{ lb/day}}{8.34 \text{ lb/gal}}$$

$$= 6.0 \text{ gpd}$$

**Example 19.16**

*Problem*

A hypochlorinator is used to disinfect the water pumped from a well. The hypochlorite solution contains 3% available chlorine. A chlorine dose of 1.3 mg/L is required for adequate disinfection throughout the system. If the flow being treated is 0.5 MGD, how many gallons per day of the hypochlorite solution will be required?

*Solution*

Calculate the lb/day chlorine required:

$$\text{Chlorine (lb/day)} = 1.3 \text{ mg/L} \times 0.5 \text{ MGD} \times 8.34 \text{ lb/gal}$$

$$= 5.4 \text{ lb/day}$$

Calculate the lb/day hypochlorite solution required:

$$\text{Hypochlorite (lb/day)} = \frac{5.4 \text{ lb/day chlorine}}{0.03}$$

$$= 180 \text{ lb/day}$$

Calculate the gpd hypochlorite solution required:

$$\text{Hypochlorite (gpd)} = \frac{180 \text{ lb/day}}{8.34 \text{ lb/gal}}$$

$$= 21.6 \text{ gpd}$$

## CALCULATING PERCENT STRENGTH OF SOLUTIONS

If a teaspoon of salt is dropped into a glass of water it gradually disappears as it dissolves in the water. A microscopic examination of the water would not show the salt. Only examination at the molecular level, which is not easily done, would show the salt and water molecules intimately mixed. If we taste the liquid, of course, we would know that the salt is there, and we could recover the salt by evaporating the water. In a solution, the molecules of the salt, the *solute*, are homogeneously dispersed among the molecules of the water, the *solvent*. This mixture of salt and water is homogeneous on a molecular level. Such a homogeneous mixture is called a *solution*. The composition of a solution can vary within certain limits. The three common states of matter are gas, liquid, and solids. In the discussion here, we are only concerned with solids (calcium hypochlorite) and liquid (sodium hypochlorite).

## CALCULATING PERCENT STRENGTH USING DRY HYPOCHLORITE

We calculate the percent strength of a chlorine solution by:

$$\% \text{ Chlorine strength} = \frac{\text{hypochlorite (lb)} \times \dfrac{\% \text{ available chlorine}}{100}}{\text{water (lb)} + \text{hypochlorite (lb)} \times \dfrac{\% \text{ available chlorine}}{100}} \times 100 \quad (19.6)$$

### Example 19.17

*Problem*

If a total of 72 ounces of calcium hypochlorite (65% available chlorine) is added to 15 gallons of water, what is the percent chlorine strength (by weight) of the solution?

*Solution*

Convert the ounces of hypochlorite to pounds hypochlorite:

$$\frac{72 \text{ ounces}}{16 \text{ ounces/pount}} = 4.5 \text{ lb chemical}$$

Then, using Equation 19.6:

$$\begin{aligned}
\% \text{ Chlorine strength} &= \frac{4.5 \text{ lb} \times 0.65}{(15 \text{ gal} \times 8.34 \text{ lb/gal}) + (4 \text{ lb} \times 0.65)} \times 100 \\
&= \frac{2.9 \text{ lb}}{125.1 \text{ lb} + 2.9 \text{ lb}} \times 100 \\
&= \frac{2.9 \times 100}{126} \\
&= 2.3\%
\end{aligned}$$

## CALCULATING PERCENT STRENGTH USING LIQUID HYPOCHLORITE

To calculate percent strength using liquid solutions, such as liquid hypochlorite, a different equation is required:

$$\begin{gathered}
\text{Liquid hypochlorite (gal)} \times 8.34 \text{ lb/gal} \times \frac{\% \text{ strength of hypochlorite}}{100} = \\
\text{hypochlorite solution (gal)} \times 8.34 \text{ lb/gal} \times \frac{\% \text{ strength of hypochlorite}}{100}
\end{gathered} \quad (19.7)$$

### Example 19.18

*Problem*

A 12% liquid hypochlorite solution is to be used in making up a hypochlorite solution. If 3.3 gallons of liquid hypochlorite are mixed with water to produce 25 gal of hypochlorite solution, what is the percent strength of the solution?

*Solution*

Referring to Equation 19.7:

$$3.3 \text{ gal} \times 8.34 \text{ lb/gal} \times \frac{12}{100} = 25 \text{ gal} \times 8.34 \text{ lb/gal} \times \frac{x}{100}$$

$$x = \frac{100 \times 3.3 \times 8.34 \times 12}{25 \times 8.34 \times 100}$$

$$= \frac{3.3 \times 12}{25}$$

$$= 1.6\%$$

## CHEMICAL USE CALCULATIONS

In a typical plant operation, the chemical use (in lb/day or gpd) is recorded each day. Such data provide a record of daily use from which the average daily use of the chemical or solution can be calculated. To calculate average use in lb/day, we use Equation 19.8. To calculate average use in gallons per day (gpd), we use Equation 19.9:

$$\text{Average use (lb/day)} = \frac{\text{total chemical used (lb)}}{\text{number of days}} \tag{19.8}$$

$$\text{Average use (gpd)} = \frac{\text{total chemical used (gal)}}{\text{number of days}} \tag{19.9}$$

To calculate the supply in inventory, we use Equation 19.10 or Equation 19.11.

$$\text{Inventory supply (days)} = \frac{\text{total chemical in inventory (lb)}}{\text{average use (lb/day)}} \tag{19.10}$$

$$\text{Inventory supply (days)} = \frac{\text{total chemical in inventory (gal)}}{\text{average use (gpd)}} \tag{19.11}$$

### Example 19.19

*Problem*

The pounds (lb) of calcium hypochlorite used each day for a week are given below. Based on the data, what was the average lb/day hypochlorite chemical use during the week?

| | |
|---|---|
| Monday, 50 lb/day | Friday, 56 lb/day |
| Tuesday, 55 lb/day | Saturday, 51lb/day |
| Wednesday, 51 lb/day | Sunday, 48 lb/day |
| Thursday, 46 lb/day | |

*Solution*

Referring to Equation 19.8:

$$\text{Average use (lb/day)} = \frac{357}{7}$$

$$= 51 \text{ lb/day}$$

**Example 19.20**

*Problem*

The average calcium hypochlorite use at a plant is 40 lb/day. If the chemical inventory in stock is 1100 lb, how many days of supply is this?

*Solution*

Referring to Equation 19.10:

$$\text{Inventory supply (days)} = \frac{1100 \text{ lb in inventory}}{40 \text{ lb/day average use}}$$

$$= 27.5 \text{ days}$$

# 20 Fluoridation

## TOPICS



**Note:** The key terms used in this chapter are defined as follows:

- *Fluoride* is found in many waters. It is also added to many water systems to reduce tooth decay.
- *Dental caries* are tooth decay.
- *Dental fluorosis* is the result of excessive fluoride content in drinking water that causes mottled, discolored teeth.

## WATER FLUORIDATION

As of 1989, fluoridation in the U.S. was being practiced in at least 8000 communities serving more than 126 million people. An additional 9 million residents of over 1800 additional communities were consuming water that contained at least 0.7-mg/L fluoride from natural sources. Key facts about fluoride include:

- Briefly, fluoride is seldom found in appreciable quantities in surface waters and appears in groundwater in only a few geographical regions
- Fluoride is sometimes found in a few types of igneous or sedimentary rocks
- Fluoride is toxic to humans in large quantities; it is also toxic to some animals
- Based on human experience, small concentrations of fluoride (about 1.0 mg/L in drinking water) can be beneficial

## FLUORIDE COMPOUNDS

Theoretically, any compound that forms fluoride ions in water solution can be used for adjusting the fluoride content of a water supply; however, several practical considerations are involved in the selection of compounds:

- Compound must have sufficient solubility to permit its use in routine water plant practice.
- Cation to which the fluoride ion is attached must not have any undesirable characteristics.
- Material should be relatively inexpensive and readily available in grades of size and purity suitable for its intended use.

✔ **Caution:** Fluoride chemicals, like chlorine, caustic soda, and many other chemicals used in water treatment, can constitute a safety hazard for water plant operators unless proper handling precautions are observed. It is essential for operators to be aware of the hazards associated with each individual chemical prior to its use.

The three commonly used fluoride chemicals — sodium fluoride (B701-90), sodium fluorosilicate (B702-90), and fluorosilicic acid (B703-90) — should meet the American Water Works Associations (AWWA) standards for use in water fluoridation.

### Sodium Fluoride

The first fluoride compound used in water fluoridation was *sodium fluoride*, which was selected based on the above criteria and also because its toxicity and physiological effects had been so thoroughly studied. It has become the reference standard used in measuring fluoride concentration. Other compounds came into use, but sodium fluoride is still widely used because of its unique physical characteristics. Sodium fluoride (NaF) is a white, odorless material available either as a powder or in the form of crystals of various sizes. It is a salt that in the past was manufactured by adding sulfuric acid to fluorspar and then neutralizing the mixture with sodium carbonate. It is now produced by neutralizing fluorosilicic acid with caustic soda (NaOH). Approximately 19 pounds of sodium fluoride will add 1 ppm of fluoride to 1 million gallons of water. The solubility of sodium fluoride is practically constant at 4 grams per 100 milliliters in water at temperatures generally encountered in water treatment practice (see Table 20.1).

### Sodium Fluorosilicate

Fluorosilicic acid can readily be converted into various salts, one of which — *sodium fluorosilicate* ($Na_2SiF_6$; also known as sodium silicofluoride) — is widely used as a chemical for water fluoridation.

**TABLE 20.1**
**Solubility of Fluoride Chemicals**

| Chemical | Temperature | Solubility (g per 100 mL of $H_2O$) |
|---|---|---|
| Sodium fluoride | 0.0 | 4.00 |
| | 15.0 | 4.03 |
| | 20.0 | 4.05 |
| | 25.0 | 4.10 |
| | 100.0 | 5.00 |
| Sodium fluorosilicate | 0.0 | 0.44 |
| | 25.0 | 0.76 |
| | 37.8 | 0.98 |
| | 65.6 | 1.52 |
| | 100.0 | 2.45 |
| Fluorosilicic acid | Infinite at all temperatures | |

*Source:* Reeves, T.G., *Water Fluoridation: A Manual for Water Plant Operators*. U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, Atlanta, GA, 1994, p. 17.

As with most fluorosilicates, it is generally obtained as a byproduct from the manufacture of phosphate fertilizers. Phosphate rock is ground up and treated with sulfuric acid, thus forming a gas byproduct. This gas reacts with water and forms fluorosilicic acid. When neutralized with sodium carbonate, sodium fluorosilicate will precipitate out. The conversion of fluorosilicic acid to a dry material containing a high percentage of available fluoride results in a compound that has most of the advantages of the acid with few of its disadvantages. Once it was shown that fluorosilicates form fluoride ions in water solution as readily as do simple fluoride compounds, with no difference in physiological effect, fluorosilicates were rapidly accepted for water fluoridation and in many cases have displaced the use of sodium fluoride, except in saturators. Sodium fluorosilicate is a white, odorless crystalline powder. Its solubility varies (see Table 20.1). Approximately 14 pounds of sodium fluorosilicate will add 1 ppm of fluoride to 1 million gallons of water.

### Fluorosilicic Acid

*Fluorosilicic acid* ($H_2SiF_6$), also known as hydrofluorosilicic or silicofluoric acid, is a 20 to 35% aqueous solution with a formula weight of 144.08. It is a straw-colored, transparent, fuming, corrosive liquid with a pungent odor and an irritating action on the skin. Solutions of 20 to 35% fluorosilicic acid exhibit a low pH (1.2) and at a concentration of 1 ppm can slightly depress the pH of poorly buffered potable waters. It must be handled with great care because it will cause a delayed burn on skin tissue. The specific gravity and density of fluorosilicic acid are given in Table 20.2.

It takes approximately 46 pounds (4.4 gallons) of 23% acid to add 1 ppm of fluoride to 1 million gallons of water. Two different processes, resulting in products with differing characteristics, are used to manufacture fluorosilicic acid. The acid is primarily produced as a byproduct of phosphate fertilizer manufacture. Phosphate rock is ground up and treated with sulfuric acid, forming a gas byproduct. Hydrofluoric acid (HF) is an extremely corrosive material. Its presence in fluorosilicic acid, whether from intentional addition (i.e., fortified acid) or from normal production processes, demands careful handling.

**TABLE 20.2**
**Properties of Fluorosilicic Acid**

| Acid (%)[a] | Specific Gravity | Density (lb/gal) |
|---|---|---|
| 0 (water) | 1.000 | 8.345 |
| 10 | 1.0831 | 9.041 |
| 20 | 1.167 | 9.739 |
| 23 | 1.191 | 9.938 |
| 25 | 1.208 | 10.080 |
| 30 | 1.250 | 10.431 |
| 35 | 1.291 | 10.773 |

*Note:* Actual densities and specific gravities will be slightly higher when distilled water is not used. Add approximately 0.2 lb/gal to density depending on impurities.

[a] Based on the other percentage being distilled water.

*Source:* Reeves, T.G., *Water Fluoridation: A Manual for Water Plant Operators*. U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, Atlanta, GA, 1994, p. 19.

**TABLE 20.3**
**Recommended Optimal Fluoride Level**

| Annual Average of Maximum Daily Air Temperatures[a] (°F) | Recommended Fluoride Concentrations (ppm) | | Recommended Control Range | | | |
|---|---|---|---|---|---|---|
| | | | Community Systems | | School Systems | |
| | Community (ppm) | School[b] (ppm) | 0.1 Below | 0.5 Above | 20% Low | 20% High |
| 40.0–53.7 | 1.2 | 5.4 | 1.1 | 1.7 | 4.3 | 6.5 |
| 53.8–58.3 | 1.1 | 5.0 | 1.0 | 1.6 | 4.0 | 6.0 |
| 58.4–63.8 | 1.0 | 4.5 | 0.9 | 1.5 | 3.6 | 5.4 |
| 63.9–70.6 | 0.9 | 4.1 | 0.8 | 1.4 | 3.3 | 4.9 |
| 70.7–79.2 | 0.8 | 3.6 | 0.7 | 1.3 | 2.9 | 4.3 |
| 79.3–90.5 | 0.7 | 3.2 | 0.6 | 1.2 | 2.6 | 3.8 |

[a] Based on temperature data obtained for a minimum of 5 years.
[b] Based on 4.5 times the optimal fluoride level for communities.

*Source:* Reeves, T.G., *Water Fluoridation: A Manual for Water Plant Operators*. U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, Atlanta, GA, 1994, p. 21.

## OPTIMAL FLUORIDE LEVELS

The recommended optimal fluoride concentrations for fluoridated water supply systems are given in Table 20.3. These levels are based on the annual average of the maximum daily air temperature in the area of the involved school or community. In areas where the mean temperature is not shown in Table 20.3, the optimal fluoride level can be determined by the following formula.

$$\text{Flouride}\left(\text{ppm}\right) = \frac{0.34}{E} \tag{20.1}$$

where $E$ is the estimated average daily water consumption for children through 10 years of age in ounces of water per pound of body weight. $E$ is obtained from the formula:

$$E = 0.038 + 0.0062 \times \text{average maximum daily air temperature (°F)} \tag{20.2}$$

In Table 20.3, the recommended control range is shifted to the high side of the optimal fluoride level for two reasons:

- It has become obvious that many water plant operators try to maintain the fluoride level in their community at the lowest level possible. The result is that the actual fluoride level in the water will vary around the lowest value in the range instead of around an optimal level.
- Some studies have shown that suboptimal fluorides are relatively ineffective in actually preventing dental caries. Even a drop of 0.2 ppm below optimal levels can reduce dental benefits significantly.

**Important Point:** In water fluoridation, underfeeding is a much more serious problem than overfeeding.

## FLUORIDATION PROCESS CALCULATIONS

### Percent Fluoride Ion in a Compound

When calculating the percent fluoride ion present in a compound, we need to know the chemical formula for the compound (e.g., NaF) and the atomic weight of each element in the compound. The first step is to calculate the molecular weight of each element in the compound (number of atoms × atomic weight = molecular weight). Then, we calculate the percent fluoride in the compound:

$$\%\text{ Fluoride in compound} = \frac{\text{molecular weight of fluoride}}{\text{molecular weight of compound}} \times 100 \tag{20.3}$$

✓ **Important Point:** The available fluoride ion concentration is abbreviated as AFI in the calculations that follow.

### Example 20.1

*Problem*

Given the following data, calculate the percent fluoride in sodium fluoride (NaF).

| Element | Number of Atoms | Atomic Weight | Molecular Weight |
|---|---|---|---|
| Na | 1 | 22.997 | 22.997 |
| F | 1 | 19.00 | 19.00 |
| Molecular weight of NaF | | | 41.997 |

*Solution*

Calculate the percent fluoride in NaF:

$$\%\text{ F in NaF} = \frac{\text{molecular weight of F}}{\text{molecular weight of NaF}} \times 100$$

$$= \frac{19.00}{41.997} \times 100$$

$$= 45.2\%$$

✓ **Key Point:** The molecular weight of hydrofluosilicic acid ($H_2SiF_6$) is 144.076 and sodium silicofluoride is 188.054 for $Na_2SiF_6$.

### Fluoride Feed Rate

Adjusting the fluoride level in a water supply to an optimal level is accomplished by adding the proper concentration of a fluoride chemical at a consistent rate. To calculate the fluoride feed rate for any fluoridation feeder in terms of pounds of fluoride to be fed per day, it is necessary to determine:

- Dosage
- Maximum pumping rate (capacity)
- Chemical purity
- Available fluoride ion concentration

The fluoride feed rate formula is a general equation used to calculate the concentration of a chemical added to water. It will be used for all fluoride chemicals, except sodium fluoride when used in a saturator.

✔ **Important point:** 1 mg/L is equal to 1 ppm.

The fluoride feed rate (the amount of chemical required to raise the fluoride content to the optimal level) can be calculated as follows:

$$\text{Fluoride feed rate (lb/day)} = \frac{\text{dosage (mg/L)} \times \text{capacity (MGD)} \times 8.34 \text{ lb/gal}}{\text{AFI} \times \text{chemical purity}} \tag{20.4}$$

If the capacity is in MGD, the fluoride feed rate will be in pounds per day. If the capacity is in gpm, the feed rate will be pounds per minute if a factor of 1 million is included in the denominator:

$$\text{Fluoride feed rate (lb/min)} = \frac{\text{dosage (mg/L)} \times \text{capacity (gpm)} \times 8.34 \text{ lb/gal}}{1{,}000{,}000 \times \text{AFI} \times \text{chemical purity}} \tag{20.5}$$

### Example 20.2 (Sodium Fluorosilicate)

*Problem*

A water plant produces 2000 gpm and the city wants to add 1.1 mg/L of fluoride. What would the fluoride feed rate be?

*Solution*

$$2000 \text{ gpm} \times 1440 \text{ min/day} = 2{,}880{,}000 \text{ gpd}$$

$$2{,}880{,}000 \text{ gpd} \div 1{,}000{,}000 = 2.88 \text{ MGD}$$

$$\text{Fluoride feed rate (lb/day)} = \frac{1.1 \text{ mg/L} \times 2.88 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.607 \times 0.985}$$

$$= 44.2 \text{ lb/day}$$

Some feed rates from equipment design data sheets are given in grams/minute. To convert to grams/minute, divide by 1440 minutes/day and multiply by 454 grams/pound:

$$\text{Fluoride feed rate (gm/min)} = 44.19 \text{ lb/day} \div 1440 \text{ min/day} \times 454 \text{ gm/lb}$$

$$\text{Fluoride feed rate} = 13.9 \text{ gm/min.}$$

### Example 20.3 (Fluorosilicic Acid)

*Problem*

If it is known that the plant rate is 4000 gpm and the dosage needed is 0.8 mg/L, what is the fluoride feed rate for 23% fluorosilicic acid (in mL/minute)?

*Solution*

Note that 1,000,000 = $10^6$.

$$\text{Fluoride feed rate (lb/min)} = \frac{\text{dosage (mg/L)} \times \text{capacity (gpm)} \times 8.34 \text{ lb/gal}}{10^6 \times \text{AFI} \times \text{chemical purity}}$$

$$= \frac{0.8 \text{ mg/L} \times 4000 \text{ gpm} \times 8.34 \text{ lb/gal}}{10^6 \times 0.79 \times 0.23}$$

$$= 0.147 \text{ lb/min}$$

✔ **Note:** A gallon of 23% fluorosilicic acid weighs 10 lb, and there are 3785 mL per gallon; thus, the following formula can be used to convert the feed rate to mL/min:

$$\text{Fluoride feed rate (mL/min)} = 0.147 \text{ lb/min} \div 10 \text{ lb/gal} \times 3785 \text{ mL/gal}$$

$$= 55.6 \text{ mL/min}$$

### Example 20.4 (Sodium Fluoride)

*Problem*

If a small water plant wishes to use sodium fluoride in a dry feeder, and the water plant has a capacity (flow) of 180 gpm, what would be the fluoride feed rate? Assume that 0.1 mg/L natural fluoride and 1.0 mg/L fluoride are desired in the drinking water.

✔ **Important Point:** The Centers for Disease Control (CDC) recommends against using sodium fluoride in a dry feeder.

*Solution*

$$\text{Fluoride feed rate (lb/min)} = \frac{\text{dosage (mg/L)} \times \text{capacity (gpm)} \times 8.34 \text{ lb/gal}}{10^6 \times \text{AFI} \times \text{chemical purity}}$$

$$= \frac{(1.0 - 0.1) \text{ mg/L} \times 180 \text{ gpm} \times 8.34 \text{ lb/gal}}{10^6 \times 0.45 \times 0.98}$$

$$= 0.003 \text{ lb/min or } 0.18 \text{ lb/hr}$$

Thus, sodium fluoride can be fed at a rate of 0.18 lb/hr to obtain 1.0 mg/L of fluoride in the water.

## Fluoride Feed Rates for Saturator

A sodium fluoride saturator is unique in that the strength of the saturated solution formed is always 18,000 ppm. This is because sodium fluoride has a solubility that is practically constant at 4.0 grams/100 milliliers water at temperatures generally encountered in water treatment. This means that each liter of solution contains 18,000 milligrams of fluoride ion (40,000 mg/L times the percent available fluoride [45%] equals 18,000 mg/L). This simplifies calculations because it eliminates the need for weighing the chemicals. A meter on the water inlet of the saturator provides this volume; all that is needed is the volume of solution added to the water:

$$\text{Fluoride feed rate (gpm)} = \frac{\text{capacity (gpm)} \times \text{dosage (mg/L)}}{18{,}000\ \text{mg/L}} \tag{20.6}$$

The fluoride feed rate will have the same units as the capacity. If the capacity is in gallons per minute (gpm), the feed rate will also be in gpm. If the capacity is in gallons per day (gpd), the feed rate will also be in gpd.

**Note:** For the mathematician, the following derivation is given.

$$\text{Fluoride feed rate (lb/min)} = \frac{\text{dosage (mg/L)} \times \text{capacity (gpm)} \times 8.34\ \text{lb/gal}}{10^6 \times \text{AFI} \times \text{chemical purity}} \tag{20.7}$$

**Note:** The chemical purity of the sodium fluoride in solution will be 4% × 8.34 lb/gal.

To change the fluoride feed rate from pounds of dry feed to gallons of solution, divide by the concentration of sodium fluoride and the density of the solution (water):

$$\begin{aligned}\text{Fluoride feed rate (gal/min)} &= \frac{\text{capacity (gpm)} \times \text{dosage (mg/L)} \times 8.34\ \text{lb/gal}}{10^6 \times \text{AFI} \times \text{chemical purity}} \\ &= \frac{\text{capacity (gpm)} \times \text{dosage (mg/L)} \times 8.34\ \text{lb/gal}}{10^6 \times 0.45 \times 4\% \times 8.34\ \text{lb/gal}} \\ &= \frac{\text{capacity (gpm)} \times \text{dosage (mg/L)}}{10^6 \times 0.45 \times 0.04} \\ &= \frac{\text{capacity (gpm)} \times \text{dosage (mg/L)}}{18{,}000\ \text{mg/L2}}\end{aligned} \tag{20.8}$$

### Example 20.5 (Feed Rate for Saturator)

*Problem*

A water plant produces 1.0 MGD and has less than 0.1 mg/L of natural fluoride. What would the fluoride feed rate be to obtain 1.0 mg/L in the water?

*Solution*

$$\begin{aligned}\text{Fluoride feed rate (gpd)} &= \frac{\text{capacity (gpd)} \times \text{dosage (mg/L)}}{18{,}000\ \text{mg/L}} \\ &= \frac{1{,}000{,}000\ \text{gpd} \times 1.0\ \text{mg/L}}{18{,}000\ \text{mg/L}} \\ &= 55.6\ \text{gpd}\end{aligned}$$

Thus, it takes approximately 56 gallons of saturated solution to treat 1 MG of water at a dose of 1.0 mg/L.

## Calculated Dosages

Some states require records to be kept regarding the amount of chemical used and the theoretical concentration of chemical in the water to be determined mathematically. In order to find the theoretical concentration of fluoride, the calculated dosage must be determined. Adding the

calculated dosage to the natural fluoride level in the water supply will yield the theoretical concentration of fluoride in the water. This number, the theoretical concentration, is calculated as a safety precaution to help ensure that an overfeed or accident does not occur. It is also an aid in solving troubleshooting problems. If the theoretical concentration is significantly higher or lower than the measured concentration, steps should be taken to determine the discrepancy. The fluoride feed rate formula can be changed to find the calculated dosage as follows:

$$\text{Dosage}\left(\text{mg/L}\right) = \frac{\text{fluoride feed rate}\left(\text{lb/day}\right) \times \text{AFI} \times \text{chemical purity}}{\text{capacity}\left(\text{MGD}\right) \times 8.34\ \text{lb/gal}} \tag{20.9}$$

When the fluoride feed rate is changed to fluoride fed and the capacity is changed to actual daily production of water in the water system, then the dosage becomes the *calculated dosage*. The units remain the same, except that the fluoride feed rate changes from lb/d to lb and actual production changes from MGD to MG (million gallons) (the day units cancel).

✔ **Note:** The amount of fluoride fed (lb) will be determined over a time period (day, week, month, etc.) and the actual production will be determined over the same time period.

$$\text{Calculated dosage}\left(\text{mg/L}\right) = \frac{\text{fluoride fed}\left(\text{lb}\right) \times \text{AFI} \times \text{chemical purity}}{\text{actual production}\left(\text{MG}\right) \times 8.34\ \text{lb/gal}} \tag{20.10}$$

The numerator of the equation gives the pounds of fluoride ion added to the water, while the denominator gives the million pounds of water treated. Pounds of fluoride divided by million pounds of water equals ppm or mg/L.

The formula for calculated dosage for the saturator is as follows:

$$\text{Calculated dosage}\left(\text{mg/L}\right) = \frac{\text{solution fed}\left(\text{gal}\right) \times 18{,}000\ \text{mg/L}}{\text{actual production}\left(\text{gal}\right)} \tag{20.11}$$

Determining the calculated dosage for an unsaturated sodium fluoride solution is based upon the particular strength of the solution. For example, a 2% strength solution is equal to 8550 mg/L. The percent strength is based on the pounds of sodium fluoride dissolved into a certain amount of water. For example, find the percent solution if 6.5 lb of sodium fluoride are dissolved in 45 gallons of water:

$$45\ \text{gal} \times 8.34\ \text{lb/gal} = 375\ \text{lb of water}$$

$$\frac{6.5\ \text{lb NaF}}{375\ \text{lb H}_2\text{O}} = 1.7\%\ \text{NaF solution}$$

This means that 6.5 lb of fluoride chemical dissolved in 45 gallons of water will yield a 1.7% solution. To find the solution concentration of an unknown sodium fluoride solution, use the following formula:

$$\text{Solution concentration} = \frac{18{,}000\ \text{mg/L} \times \text{solution strength}\left(\%\right)}{4\%} \tag{20.12}$$

**Example 20.6**

*Problem*

Assume that 6.5 lb of NaF is dissolved in 45 gallons of water, as previously given. What would be the solution concentration? Solution strength is 1.7% (see above).

*Solution*

$$\text{Solution concentration} = \frac{18{,}000\ \text{mg/L} \times \text{solution strength}\ (\%)}{4\%}$$

$$= \frac{18{,}000\ \text{mg/L} \times 1.7\%}{4\%}$$

$$= 7650\ \text{mg/L}$$

✔ **Note:** The calculated dosage formula for an unsaturated sodium fluoride solution is:

$$\text{Calculated dosage}\ (\text{mg/L}) = \frac{\text{solution fed (gal)} \times \text{solution concentration (mg/L)}}{\text{actual production (gal)}}$$

✔ **Caution:** The CDC recommends against the use of unsaturated sodium fluoride solution in water fluoridation.

## Calculated Dosage Problems

### Example 20.7 (Sodium Fluorosilicate Dosage)

*Problem*

A plant uses 65 lb of sodium fluorosilicate to treat 5,540,000 gallons of water in one day. What is the calculated dosage?

*Solution*

$$\text{Calculated dosage}\ (\text{mg/L}) = \frac{\text{fluoride fed (lb)} \times \text{AFI} \times \text{purity}}{\text{actual production (MG)} \times 8.34\ \text{lb/gal}}$$

$$= \frac{65\ \text{lb} \times 0.607 \times 0.985}{5540\ \text{MG} \times 8.34\ \text{lb/gal}}$$

$$= 0.84\ \text{mg/L}$$

### Example 20.8 (Fluorosilicic Acid Dosage)

*Problem*

A plant uses 43 lb of fluorosilicic acid to treat 1,226,000 gallons of water. Assume the acid is 23% purity. What is the calculated dosage?

*Solution*

$$\text{Calculated dosage}\ (\text{mg/L}) = \frac{\text{fluoride fed (lb)} \times \text{AFI} \times \text{purity}}{\text{actual production (MG)} \times 8.34\ \text{lb/gal}}$$

$$= \frac{43\ \text{lb} \times 0.792 \times 0.23}{1.226\ \text{MG} \times 8.34\ \text{lb/gal}}$$

$$= 0.77\ \text{mg/L}$$

✔ **Note:** The calculated dosage is 0.77 mg/L. If the natural fluoride level is added to this dosage, then it should equal what the actual fluoride level is in the drinking water.

**Example 20.9 (Dry Sodium Fluoride Dosage)**

*Problem*

A water plant feeds sodium fluoride in a dry feeder. They use 5.5 lb of the chemical to fluoridate 240,000 gallons of water. What is the calculated dosage?

*Solution*

$$\text{Calculated dosage (mg/L)} = \frac{\text{fluoride fed (lb)} \times \text{AFI} \times \text{purity}}{\text{actual production (MG)} \times 8.34 \text{ lb/gal}}$$

$$= \frac{5.5 \text{ lb} \times 0.45 \times 0.98}{0.24 \text{ MG} \times 8.34 \text{ lb/gal}}$$

$$= 1.2 \text{ mg/L}$$

**Example 20.10 (Sodium Fluoride Saturator Dosage)**

*Problem*

A plant uses 10 gallons of sodium fluoride from its saturator to treat 200,000 gallons of water. What is the calculated dosage?

*Solution*

$$\text{Calculated dosage (mg/L)} = \frac{\text{solution fed (gal)} \times 18{,}000 \text{ mg/L}}{\text{actual production (gal)}}$$

$$= \frac{10 \text{ gal} \times 18{,}000 \text{ mg/L}}{200{,}000 \text{ gal}}$$

$$= 0.9 \text{ mg/L}$$

**Example 20.11 (Sodium Fluoride Unsaturated Solution Dosage)**

*Problem*

A water plant adds 93 gallons per day of a 2% solution of sodium fluoride to fluoridate 800,000 gal/day. What is the calculated dosage?

*Solution*

$$\text{Solution concentration (mg/L)} = \frac{18{,}000 \text{ mg/L} \times \text{solution strength (\%)}}{4\%}$$

$$= \frac{18{,}000 \text{ mg/L} \times 0.02}{0.04}$$

$$= 9000 \text{ mg/L}$$

$$\text{Calculated dosage (mg/L)} = \frac{\text{solution fed (gal)} \times \text{solution concentration (mg/L)}}{\text{actual production (gal)}}$$

$$= \frac{93 \text{ gal} \times 9000 \text{ mg/L}}{800{,}000 \text{ gal}}$$

$$= 1.05 \text{ mg/L}$$

# 21 Water Softening

## TOPICS



## WATER HARDNESS

Hardness in water is caused by the presence of certain positively charged metallic ions in solution in the water. The most common of these hardness-causing ions are calcium and magnesium; others include iron, strontium, and barium. The two primary constituents of water that determine the hardness of water are calcium and magnesium. If the concentration of these elements in the water is known, the total hardness of the water can be calculated. To make this calculation, the equivalent weights of calcium, magnesium, and calcium carbonate must be known; the equivalent weights are given below.

**Equivalent Weights**

| | |
|---|---|
| Calcium (Ca) | 20.04 |
| Magnesium (Mg) | 12.15 |
| Calcium carbonate ($CaCO_3$) | 50.045 |

### Calculating Calcium Hardness as $CaCO_3$

The hardness (in mg/L as $CaCO_3$) for any given metallic ion is calculated using Equation 21.1.

$$\frac{\text{calcium hardness (mg/L) as } CaCO_3}{\text{equivalent weight of } CaCO_3} = \frac{\text{calcium (mg/L)}}{\text{equivalent weight of calcium}} \tag{21.1}$$

**Example 21.1**

*Problem*

A water sample has calcium content of 51 mg/L. What is this calcium hardness expressed as $CaCO_3$?

*Solution*

Referring to Equation 21.1:

$$\frac{x \text{ mg/L}}{50.045} = \frac{51 \text{ mg/L}}{20.04}$$

$$x = \frac{51 \times 50.045}{20.45}$$

$$= 124.8 \text{ mg/L Ca as } CaCO_3$$

**Example 21.2**

*Problem*

The calcium content of a water sample is 26 mg/L. What is this calcium hardness expressed as $CaCO_3$?

*Solution*

Again referring to Equation 21.1:

$$\frac{x \text{ mg/L}}{50.045} = \frac{26 \text{ mg/L}}{20.04}$$

$$x = \frac{26 \times 50.045}{20.45}$$

$$= 64.9 \text{ mg/L Ca as } CaCO_3$$

## Calculating Magnesium Hardness as $CaCO_3$

To calculate magnesium harness, we use Equation 21.2:

$$\frac{\text{magnesium hardness (m/L) as } CaCO_3}{\text{equivalent weight of } CaCO_3} = \frac{\text{magnesium (mg/L)}}{\text{equivalent weight of magnesium}} \tag{21.2}$$

**Example 21.3**

*Problem*

A sample of water contains 24 mg/L magnesium. Express this magnesium hardness as $CaCO_3$.

*Solution*

Referring to Equation 21.2:

$$\frac{x \text{ mg/L}}{50.045} = \frac{24 \text{ mg/L}}{12.15}$$

$$x = \frac{24 \times 50.045}{12.15}$$

$$= 98.9 \text{ mg/L}$$

**Example 21.4**

*Problem*

The magnesium content of a water sample is 16 mg/L. Express this magnesium hardness as $CaCO_3$.

*Solution*

Again referring to Equation 21.2:

$$\frac{x \text{ mg/L}}{50.045} = \frac{16 \text{ mg/L}}{12.15}$$

$$x = \frac{16 \times 50.045}{12.15}$$

$$= 65.9 \text{ mg/L Mg as } CaCO_3$$

## Calculating Total Hardness

Calcium and magnesium ions are the primary cause of hardness in water. To find total hardness, we simply add the concentrations of calcium and magnesium ions, expressed in terms of calcium carbonate ($CaCO_3$):

$$\text{Total hardness (mg/L) as } CaCO_3 = \text{calcium hardness (mg/L) as } CaCO_3 + \text{magnesium hardness (mg/L) as } CaCO_3 \tag{21.3}$$

### Example 21.5

*Problem*

A sample of water has calcium content of 70 mg/L as $CaCO_3$ and magnesium content of 90 mg/L as $CaCO_3$.

*Solution*

Referring to Equation 21.3:

$$\text{Total hardness (mg/L)} = 70 \text{ mg/L} + 90 \text{ mg/L}$$

$$= 160 \text{ mg/L as } CaCO_3$$

### Example 21.6

*Problem*

Determine the total hardness as $CaCO_3$ of a sample of water that has calcium content of 28 mg/L and magnesium content of 9 mg/L.

*Solution*

Express calcium and magnesium in terms of $CaCO_3$:

$$\frac{\text{calcium hardness (mg/L) as } CaCO_3}{\text{equivalent weight of } CaCO_3} = \frac{\text{calcium (mg/L)}}{\text{equivalent weight of calcium}}$$

$$\frac{x \text{ mg/L}}{50.045} = \frac{28 \text{ mg/L}}{20.04}$$

$$x = 69.9 \text{ mg/L Mg as } CaCO_3$$

$$\frac{\text{magnesium hardness (mg/L) as } CaCO_3}{\text{equivalent weight of } CaCO_3} = \frac{\text{magnesium (mg/L)}}{\text{equivalent weight of magnesium}}$$

$$\frac{x \text{ mg/L}}{50.045} = \frac{9 \text{ mg/L}}{12.15}$$

$$x = 37.1 \text{ mg/L Mg as } CaCO_3$$

Now, total hardness can be calculated using Equation 21.3:

$$\text{Total hardness (mg/L)} = 69.9 \text{ mg/L} + 37.1 \text{ mg/L}$$

$$= 107 \text{ mg/L as } CaCO_3$$

## Calculating Carbonate and Noncarbonate Hardness

As mentioned, total hardness is comprised of calcium and magnesium hardness. Once total hardness has been calculated, it is sometimes used to determine another expression hardness — carbonate and noncarbonate. When hardness is numerically greater than the sum of bicarbonate and carbonate alkalinity, that amount of hardness equivalent to the total alkalinity (both in units of mg $CaCO_3$/L) is referred to as the *carbonate hardness*; the amount of hardness in excess of this is the *noncarbonate hardness*. When the hardness is numerically equal to or less than the sum of carbonate and noncarbonate alkalinity, all hardness is carbonate hardness, and noncarbonate hardness is absent.

Again, the total hardness is comprised or carbonate hardness and noncarbonate hardness:

$$\text{Total hardness} = \text{carbonate hardness} + \text{noncarbonate hardness} \tag{21.4}$$

When the alkalinity (as $CaCO_3$) is greater than the total hardness, all the hardness is carbonate hardness:

$$\text{Total hardness (mg/L) as } CaCO_3 = \text{carbonate hardness (mg/L) as } CaCO_3 \tag{21.5}$$

When the alkalinity (as $CaCO_3$) is less than the total hardness, then the alkalinity represents carbonate hardness and the balance of the hardness is noncarbonate hardness:

$$\begin{aligned}\text{Total hardness (mg/L) as } CaCO_3 = {} & \text{carbonate hardness (mg/L) as } CaCO_3 + \\ & \text{noncarbonate hardness (mg/L) as } CaCO_3\end{aligned} \tag{21.6}$$

When carbonate hardness is represented by the alkalinity:

$$\begin{aligned}\text{Total hardness (mg/L) as } CaCO_3 = {} & \text{alkalinity (mg/L) as } CaCO_3 + \\ & \text{noncarbonate hardness (mg/L) as } CaCO_3\end{aligned} \tag{21.7}$$

### Example 21.7

*Problem*

A water sample contains 110 mg/L alkalinity as $CaCO_3$ and 105 mg/L total hardness as $CaCO_3$. What is the carbonate and noncarbonate hardness of the sample?

*Solution*

Because the alkalinity is greater than the total hardness, all the hardness is carbonate hardness:

$$\text{Total hardness (mg/L) as } CaCO_3 = \text{Carbonate hardness (mg/L) as } CaCO_3$$

$$105 \text{ mg/L as } CaCO_3 = \text{Carbonate hardness}$$

No noncarbonate hardness is present in this water.

### Example 21.8

*Problem*

The alkalinity of a water sample is 80 mg/L as $CaCO_3$. If the total hardness of the water sample is 112 mg/L as $CaCO_3$, what is the carbonate and noncarbonate hardness (in mg/L as $CaCO_3$)?

*Solution*

Alkalinity is less than total hardness; therefore, both carbonate and noncarbonate hardness will be present in the hardness of the sample. Referring to Equation 21.6,

$$112 \text{ mg/L} = 80 \text{ mg/L} - x \text{ mg/L}$$

$$112 \text{ mg/L} - 80 \text{ mg/L} = x \text{ mg/L}$$

$$x = 32 \text{ mg/L noncarbonate hardness}$$

## ALKALINITY DETERMINATION

Alkalinity measures the acid-neutralizing capacity of a water sample. It is an aggregate property of the water sample and can be interpreted in terms of specific substances only when a complete chemical composition of the sample is also performed. The alkalinity of surface waters is primarily due to the carbonate, bicarbonate, and hydroxide content and is often interpreted in terms of the concentrations of these constituents. The higher the alkalinity, the greater the capacity of the water to neutralize acids; conversely, the lower the alkalinity, the less the neutralizing capacity. To detect the different types of alkalinity, the water is tested for phenolphthalein and total alkalinity, using Equation 21.8 and Equation 21.9:

$$\text{Phenolphthalein alkalinity (mg/L) as } CaCO_3 = \frac{A \times N \times 50{,}000}{\text{mL of sample}} \tag{21.8}$$

$$\text{Total alkalinity (mg/L) as } CaCO_3 = \frac{B \times N \times 50{,}000}{\text{mL of sample}} \tag{21.9}$$

where

$A$ = titrant (mL) used to pH 8.3
$B$ = titrant (mL) used to titrate to pH 4.5
$N$ = normality of the acid (0.02 $N$ $H_2SO_4$ for this alkalinity test)
50,000 = a conversion factor to change the normality into units of $CaCO_3$

### Example 21.9

*Problem*

A 100-mL water sample is tested for phenolphthalein alkalinity. If 1.3-mL titrant is used to pH 8.3 and the sulfuric acid solution has a normality of 0.02 *N*, what is the phenolphthalein alkalinity of the water?

*Solution*

Referring to Equation 21.8:

$$\text{Phenolphthalein alkalinity}\left(\text{mg/L as CaCO}_3\right) = \frac{A \times N \times 50,000}{\text{mL of sample}}$$

$$= \frac{1.3 \text{ mL} \times 0.02\ N \times 50,000}{100 \text{ mL}}$$

$$= 13 \text{ mg/L as CaCO}_3$$

### Example 21.10

*Problem*

A 100-mL sample of water is tested for alkalinity. The normality of the sulfuric acid used for titrating is 0.02 *N*. If 0 mL is used to pH 8.3, and 7.6 mL titrant is used to pH 4.5, what is the phenolphthalein and total alkalinity of the sample?

*Solution*

$$\text{Phenolphthalein alkalinity}\left(\text{mg/L as CaCO}_3\right) = \frac{0 \text{ mL} \times 0.02\,N \times 50,000}{100 \text{ mL}}$$

$$= 0 \text{ mg/L}$$

$$\text{Total alkalinity}\left(\text{mg/L as CaCO}_3\right) = \frac{7.6 \text{ mL} \times 0.02\,N \times 50,000}{100 \text{ mL}}$$

$$= 76 \text{ mg/L}$$

## Determining Bicarbonate, Carbonate, and Hydroxide Alkalinity

Interpretation of phenolphthalein and total alkalinity test results (assuming all of the alkalinity found is due to carbonate, bicarbonate, or hydroxide) can be made using calculations based on the values given in Table 21.1.

### Example 21.11

*Problem*

A water sample is tested for phenolphthalein and total alkalinity. If the phenolphthalein alkalinity is 10 mg/L as $CaCO_3$ and the total alkalinity is 52 mg/L as $CaCO_3$, what are the bicarbonate, carbonate, and hydroxide alkalinities of the water?

**TABLE 21.1**
**Interpretation of Results Values**

| | Alkalinity (mg/L as $CaCO_3$) | | |
|---|---|---|---|
| **Results of Titration** | **Bicarbonate Alkalinity** | **Carbonate Alkalinity** | **Hydroxide Alkalinity** |
| P = 0 | T | 0 | 0 |
| P < ½ T | T – 2P | 2P | 0 |
| P = ½ T | 0 | 2P | 0 |
| P > ½ T | 0 | 2T – 2P | 2P – T |
| P = T | 0 | 0 | T |

*Note*: P = phenolphthalein alkalinity; T = total alkalinity.

*Source:* APHA, *Standard Methods*, Vol. 19, American Public Health Association, Washington, D.C., 1995, p. 2–28.

### *Solution*

Based on titration test results, phenolphthalein alkalinity (10 mg/L) is less than half of the total alkalinity (52 mg/L ÷ 2 = 26 mg/L; see Table 21.1); therefore, each type of alkalinity is calculated as follows:

$$\begin{aligned}
\text{Bicarbonate alkalinity} &= \text{T} - 2\text{P} \\
&= 52 \text{ mg/L} - 2(10 \text{ mg/L}) \\
&= 52 \text{ mg/L} - 20 \text{ mg/L} \\
&= 32 \text{ mg/L as CaCO}_3 \\
\text{Carbonate alkalinity} &= 2\text{P} \\
&= 2(10 \text{ mg/L}) \\
&= 20 \text{ mg/L as CaCO}_3 \\
\text{Hydroxide alkalinity} &= 0 \text{ mg/L as CaCO}_3
\end{aligned}$$

## Example 21.12

### *Problem*

Results of alkalinity titrations on a water sample are as follows:

Sample was 100 mL
1.4 mL titrant was used to pH 8.3
2.4 mL total titrant was used to pH 4.5
Acid normality was 0.02 *N* $H_2SO_4$

What is the phenolphthalein, total bicarbonate, carbonate and hydroxide alkalinity?

*Solution*

$$\text{Phenolphthalein alkalinity } (\text{mg/L as CaCO}_3) = \frac{1.4 \text{ mL} \times 0.02\,N \times 50{,}000}{100 \text{ mL}}$$

$$= 14 \text{ mg/L as CaCO}_3$$

$$\text{Total alkalinity } (\text{mg/L as CaCO}_3) = \frac{2.4 \text{ mL} \times 0.02\,N \times 50{,}000}{100 \text{ mL}}$$

$$= 24 \text{ mg/L as CaCO}_3$$

Now use Table 21.1 to calculate the other alkalinity constituents (P > ½ T):

$$\text{Bicarbonate alkalinity} = 0 \text{ mg/L as CaCO}_3$$

$$\text{Carbonate alkalinity} = 2\text{T} - 2\text{P}$$

$$= 2(24 \text{ mg/L}) - 2(14 \text{ mg/L})$$

$$= 20 \text{ mg/L as CaCO}_3$$

$$\text{Hydroxide alkalinity} = 2\text{P} - \text{T}$$

$$= 2(14 \text{ mg/L}) - (24 \text{ mg/L})$$

$$= 4 \text{ mg/L as CaCO}_3$$

## LIME DOSAGE CALCULATION FOR REMOVAL OF CARBONATE HARDNESS

The lime–soda ash water-softening process uses lime, $Ca(OH)_2$, and soda ash, $Na_2CO_3$, to precipitate hardness from solution. Carbonate hardness (calcium and magnesium bicarbonates) is complexed by lime. Noncarbonate hardness (calcium and magnesium sulfates or chlorides) requires the addition of soda ash for precipitation. The molecular weights of various chemicals and compounds used in lime–soda as softening calculations are as follows:

| Chemical or Compound | Molecular Weight |
|---|---|
| Quicklime ($CaO_2$) | 56 |
| Hydrated lime ($Ca(OH)_2$) | 74 |
| Magnesium ($Mg^{2+}$) | 24.3 |
| Carbon dioxide ($CO_2$) | 44 |
| Magnesium hydroxide ($Mg(OH)_2$) | 58.3 |
| Soda ash ($Na_2CO_3$) | 100 |
| Alkalinity (as $CaCO_3$) | 100 |
| Hardness (as $CaCO_3$) | 100 |

To calculate quicklime or hydrated lime dosage (mg/L), use Equation 21.10:

$$\text{Quicklime (CaO) feed (mg/L)} = \frac{(A+B+C+D)\times 1.15}{\dfrac{\%\text{ purity of lime}}{100}} \tag{21.10}$$

where

$A$ = $CO_2$ in source water (mg/L as $CO_2 \times 56/44$)
$B$ = bicarbonate alkalinity removed in softening (mg/L as $CaCO_3 \times 56/100$)
$C$ = hydroxide alkalinity in softener effluent (mg/L as $CaCO_3 \times 56/100$)
$D$ = magnesium removed in softening (mg/L as $Mg^{2+} \times 56/24.3$)
1.15 = excess lime dosage (using 15% excess)

*Note:* For hydrated lime dosage, use Equation 21.10 as given for quicklime, except substitute 74 for 56 when determining *A*, *B*, *C*, and *D*.

### Example 21.13

#### *Problem*

A water sample has a carbon dioxide content of 4 mg/L as $CO_2$, total alkalinity of 130 mg/L as $CaCO_3$, and magnesium content of 26 mg/L as $Mg^{2+}$. Approximately how much quicklime (CaO × 90% purity) will be required for softening? (Assume 15% excess lime.)

#### *Solution*

Calculate the *A* to *D* factors:

$$A = CO_2\ (\text{mg/L}) \times (56/44)$$
$$= 4\ \text{mg/L} \times (56/44)$$
$$= 5\ \text{mg/L}$$
$$B = \text{Alkalinity}\ (\text{mg/L}) \times (56/100)$$
$$= 130\ \text{mg/L} \times (56/100)$$
$$= 73\ \text{mg/L}$$

$$C = 0\ \text{mg/L}$$

$$D = Mg^{2+}\ (\text{mg/L}) \times (56/24.3)$$
$$= 26\ \text{mg/L} \times (56/24.3)$$
$$= 60\ \text{mg/L}$$

Calculate the estimated quicklime dosage:

$$\text{Quicklime dosage (mg/L)} = \frac{(5\ \text{mg/L} + 73\ \text{mg/L} + 0 + 60\ \text{mg/L}) \times 1.15}{0.90}$$
$$= 176\ \text{mg/L CaO}$$

### Example 21.14

#### *Problem*

The characteristics of a water sample are as follows: 4 mg/L $CO_2$ as $CO_2$, 175 mg/L total alkalinity as $CaCO_3$, and 20 mg/L magnesium as $Mg^{2+}$. What is the estimated hydrated lime ($Ca(OH)_2$) (90% pure) dosage required for softening (in mg/L)? (Assume 15% excess lime.)

*Solution*

Determine the A to D factors:

$$A = CO_2\ (\text{mg/L}) \times (74/44)$$
$$= 4\ \text{mg/L} \times (74/44)$$
$$= 7\ \text{mg/L}$$
$$B = \text{Alkalinity}\ (\text{mg/L}) \times (74/100)$$
$$= 175\ \text{mg/L} \times (74/100)$$
$$= 130\ \text{mg/L}$$

$$C = 0\ \text{mg/L}$$

$$D = Mg^{2+}\ (\text{mg/L}) \times (74/24.3)$$
$$= 20\ \text{mg/L} \times (74/24.3)$$
$$= 61\ \text{mg/L}$$

Calculate the estimated hydrated lime dosage:

$$\text{Hydrated lime dosage (mg/L)} = \frac{(7\ \text{mg/L} + 130\ \text{mg/L} + 0 + 61\ \text{mg/L}) \times 1.15}{0.90}$$
$$= 253\ \text{mg/L Ca(OH)}_2$$

## CALCULATION FOR REMOVAL OF NONCARBONATE HARDNESS

Soda ash is used for precipitation and removal of noncarbonate hardness. To calculate the soda ash dosage required, we use, in combination, Equation 21.11 and Equation 21.12:

$$\text{Total hardness (mg/L as CaCO}_3) = \text{carbonate hardness (mg/L as CaCO}_3) + \text{noncarbonate hardness (mg/L as CaCO}_3) \tag{21.11}$$

$$\text{Soda ash (Na}_2\text{CO}_3)\text{(mg/L)} = \text{(noncarbonate) hardness (mg/L as CaCO}_3) \times (106/100) \tag{21.12}$$

### Example 21.15

*Problem*

A water sample has a total hardness of 250 mg/L as $CaCO_3$ and a total alkalinity of 180 mg/L. What soda ash dosage will be required to remove the noncarbonate hardness (in mg/L)?

*Solution*

Calculate the noncarbonate hardness using Equation 21.11:

$$\text{Total hardness (mg/L as CaCO}_3) = 250\ \text{mg/L} - 180\ \text{mg/L} = x\ \text{mg/L}$$
$$x = 70\ \text{mg/L}$$

Calculate the soda ash required using Equation 21.12:

$$\text{Soda ash (Na}_2\text{CO}_3)\text{ (mg/L)} = 70\ \text{mg/L} \times (106/100)$$
$$= 74.2\ \text{mg/L soda ash}$$

**Example 21.16**

*Problem*

Calculate the soda ash required (in mg/L) to soften water if the water has a total hardness of 192 mg/L and a total alkalinity of 103 mg/L.

*Solution*

Determine noncarbonate hardness:

$$192 \text{ mg/L} = 103 \text{ mg/L} + x \text{ mg/L}$$

$$192 \text{ mg/L} - 103 \text{ mg/L} = x$$

$$89 \text{ mg/L} = x$$

Calculate soda ash required:

$$\text{Soda ash (mg/L)} = (89 \text{ mg/L} \times 106)/100$$

$$= 94 \text{ mg/L soda ash}$$

## RECARBONATION CALCULATION

Recarbonation involves the reintroduction of carbon dioxide into the water, either during or after lime softening, lowering the pH of the water to about 10.4. After the addition of soda ash, recarbonation lowers the pH of the water to about 9.8, promoting better precipitation of calcium carbonate and magnesium hydroxide. Equation 21.13 and Equation 21.14 are used to estimate carbon dioxide dosage.

$$\text{Excess lime (mg/L)} = (A + B + C + D) \times 0.15 \tag{21.13}$$

$$\begin{aligned}\text{Total } CO_2 \text{ dosage } (\text{mg/L}) = &\left[\text{Ca (OH)}_2 \text{ excess } (\text{mg/L}) \times (44)/74\right] + \\ &\left[\text{Mg}^{2+} \text{ residual } (\text{mg/L}) \times (44)/24.3\right]\end{aligned} \tag{21.14}$$

**Example 21.17**

*Problem*

The $A$, $B$, $C$, and $D$ factors of the excess lime equation have been calculated as follows: $A$ = 14 mg/L; $B$ = 126 mg/L; $C$ = 0; and $D$ = 66 mg/L. If the residual magnesium is 5 mg/L, what is the carbon dioxide (in mg/L) required for recarbonation?

*Solution*

Calculate the excess lime concentration:

$$\begin{aligned}\text{Excess lime } (\text{mg/L}) &= (A + B + C + D) \times 0.15 \\ &= (14 \text{ mg/L} + 126 \text{ mg/L} + 0 + 66 \text{ mg/L}) \times 0.15 \\ &= 31 \text{ mg/L}\end{aligned}$$

Determine the required carbon dioxide dosage:

$$\text{Total } CO_2 \text{ dosage (mg/L)} = (31 \text{ mg/L} \times 44)/74 + (5 \text{ mg/L} \times 44)/24.3$$
$$= 18 \text{ mg/L} + 9 \text{ mg/L}$$
$$= 27 \text{ mg/L}$$

**Example 21.18**

*Problem*

The $A$, $B$, $C$, and $D$ factors of the excess lime equation have been calculated as: $A$ = 10 mg/L; $B$ = 87 mg/L; $C$ = 0; $D$ = 111 mg/L. If the residual magnesium is 5 mg/L, what carbon dioxide dosage would be required for recarbonation?

*Solution*

The excess lime is:

$$\text{Excess lime (mg/L)} = (A + B + C + D) \times 0.15$$
$$= (10 \text{ mg/L} + 87 \text{ mg/L} + 0 + 111 \text{ mg/L}) \times 0.15$$
$$= 208 \times 0.15$$
$$= 31 \text{ mg/L}$$

The required carbon dioxide dosage for recarbonation is:

$$\text{Total } CO_2 \text{ dosage (mg/L)} = (31 \text{ mg/L} \times 44)/74 + (5 \text{ mg/L} \times 44)/24.3$$
$$= 18 \text{ mg/L} + 9 \text{ mg/L}$$
$$= 27 \text{ mg/L } CO_2$$

## CALCULATING FEED RATES

The appropriate chemical dosage for various unit processes is typically determined by laboratory or pilot-scale testing (e.g., jar testing, pilot plant), monitoring, and historical experience. Once the chemical dosage is determined, the feed rate can be calculated using Equation 21.15. Once the chemical feed rate is known, this value must be translated into a chemical feeder setting.

$$\text{Feed rate (lb/day)} = \text{Flow rate (MGD)} \times \text{chemical dose (mg/L)} \times 8.34 \text{ lb/gal} \qquad (21.15)$$

To calculate the lb/min chemical required, we use Equation 21.16:

$$\text{Chemical (lb/min)} = \frac{\text{chemical (lb/day)}}{1440 \text{ min/day}} \qquad (21.16)$$

**Example 21.19**

*Problem*

Jar tests indicate that the optimum lime dosage is 200 mg/L. If the flow to be treated is 4.0 MGD, what should be the chemical feeder setting in lb/day and lb/min?

*Solution*

Calculate the lb/day feed rate using Equation 21.15:

$$\begin{aligned}\text{Feed rate (lb/day)} &= \text{Flow rate (MGD)} \times \text{chemical dose (mg/L)} \times 8.34 \text{ lb/gal}\\ &= 200 \text{ mg/L} \times 4.0 \text{ MGD} \times 8.34 \text{ lb/gal}\\ &= 6672 \text{ lb/day}\end{aligned}$$

Convert this feed rate to lb/min:

$$\begin{aligned}\text{Feed rate}\left(\text{lb/min}\right) &= \frac{6672 \text{ lb/day}}{1440 \text{ min/day}}\\ &= 4.6 \text{ lb/min}\end{aligned}$$

**Example 21.20**

*Problem*

What should be the lime dosage setting (in lb/day and lb/hr) if the optimum lime dosage has been determined to be 125 mg/L and the flow to be treated is 1.1 MGD?

*Solution*

The lb/day feed rate for lime is:

$$\begin{aligned}\text{Lime}\left(\text{lb/day}\right) &= \text{lime}\left(\text{mg/L}\right) \times \text{flow (MGD)} \times 8.34 \text{ lb/gal}\\ &= 125 \text{ mg/L} \times 1.1 \text{ MGD} \times 8.34 \text{ lb/day}\\ &= 1147 \text{ lb/day}\end{aligned}$$

Convert this to a lb/min feed rate:

$$\begin{aligned}\text{Lime}\left(\text{lb/min}\right) &= \frac{1147 \text{ lb/day}}{24 \text{ hr/day}}\\ &= 48 \text{ lb/hr}\end{aligned}$$

## ION EXCHANGE CAPACITY

An ion exchange softener is a common alternative to the use of lime and soda ash for softening water. Natural water sources contain dissolved minerals that dissociate in water to form charged particles called *ions*. Of main concern are the positively charged ions of calcium, magnesium, and

sodium; bicarbonate, sulfate, and chloride are the normal negatively charged ions of concern. An ion exchange medium, called *resin*, is a material that exchanges a hardness-causing ion for another one that does not cause hardness, holds the new ion temporarily, and then releases it when a regenerating solution is poured over the resin. The removal capacity of an exchange resin is generally reported as grains (gr) of hardness removal per cubic foot ($ft^3$) of resin. To calculate the removal capacity of the softener, we use:

$$\text{Exchange capacity (grains)} = \text{Removal capacity (grains/cu ft)} \times \text{media volume (cu ft)} \quad (21.17)$$

**Example 21.21**

*Problem*

The hardness removal capacity of an exchange resin is 24,000 grains/cu ft. If the softener contains a total of 70 cu ft of resin, what is the total exchange capacity (in grains) of the softener?

*Solution*

Referring to Equation 21.17:

$$\text{Exchange capacity (grains)} = 22{,}000 \text{ grains/cu ft} \times 70 \text{ cu ft}$$

$$= 1{,}540{,}000 \text{ grains}$$

**Example 21.22**

*Problem*

An ion-exchange water softener has a diameter of 7 ft. The depth of resin is 5 ft. If the resin has a removal capacity of 22-kilograins/cu ft, what is the total exchange capacity of the softener (in grains)?

*Solution*

Before the exchange capacity of a softener can be calculated, the cu ft resin volume must be known:

$$\text{Volume (cu ft)} = 0.785 \times D^2 \times \text{depth (ft)}$$

$$= 0.785 \times 7 \text{ ft} \times 7 \text{ ft} \times 5 \text{ ft}$$

$$= 192 \text{ cu ft}$$

Calculate the exchange capacity of the softener using Equation 21.17:

$$\text{Exchange capacity (grains)} = 22{,}000 \text{ grains/cu ft} \times 192 \text{ cu ft}$$

$$= 4{,}224{,}000 \text{ grains}$$

## Water Treatment Capacity

To calculate when the resin must be regenerated (based on volume of water treated), we must know the exchange capacity of the softener and the hardness of the water:

$$\text{Water treatment capacity (gal)} = \frac{\text{exchange capacity (grains)}}{\text{hardness (grains/gallon)}} \quad (21.18)$$

### Example 21.23

*Problem*

An ion-exchange softener has an exchange capacity of 2,455,000 grains. If the hardness of the water to be treated is 18.6 grains/gallon, how many gallons of water can be treated before regeneration of the resin is required?

*Solution*

Referring to Equation 21.18:

$$\text{Water treatment capacity (gal)} = \frac{2,455,000 \text{ grains}}{18.6 \text{ gpg}}$$

$$= 131,989 \text{ gallons water treated}$$

### Example 21.24

*Problem*

An ion-exchange softener has an exchange capacity of 5,500,000 grains. If the hardness of the water to be treated is 14.8 grains/gallon, how many gallons of water can be treated before regeneration of the resin is required?

*Solution*

Again referring to Equation 21.18:

$$\text{Water treatment capacity (gal)} = \frac{5,500,000 \text{ grains}}{14.8 \text{ gpg}}$$

$$= 371,622 \text{ gallons water treated}$$

### Example 21.25

*Problem*

The hardness removal capacity of an ion-exchange resin is 25 kilograins/cu ft. The softener contains a total of 160 cu ft of resin. If the water to be treated contains 14.0 gpg hardness, how many gallons of water can be treated before regeneration of the resin is required?

*Solution*

Both the water hardness and the exchange capacity of the softener must be determined before the gallons of water can be calculated:

$$\text{Exchange capacity (grains)} = 25,000 \text{ grains/cu ft} \times 160 \text{ cu ft}$$

$$= 4,000,000 \text{ grains}$$

Calculate the gallons water treated:

$$\text{Water treatment capacity (gal)} = \frac{4,000,000 \text{ grains}}{14.0 \text{ gpg}}$$

$$= 285,714 \text{ gallons water treated}$$

### TREATMENT TIME CALCULATION (UNTIL REGENERATION REQUIRED)

After calculating the total number of gallons water to be treated (before regeneration), we can also calculate the operating time required to treat that amount of water:

$$\text{Operating time (hr)} = \frac{\text{water treatment (gal)}}{\text{flow rate (gph)}} \tag{21.19}$$

#### Example 21.26

*Problem*

An ion-exchange softener can treat a total of 642,000 gallons before regeneration is required. If the flow rate treated is 25,000 gph, how many hours of operation do we have before regeneration is required?

*Solution*

Referring to Equation 21.19:

$$\text{Operating time (hr)} = \frac{\text{water treated (gal)}}{\text{flow rate (gph)}}$$

$$= \frac{642,000 \text{ gal}}{25,000 \text{ gph}}$$

$$= 25.7 \text{ hr of operation before regeneration}$$

#### Example 21.27

*Problem*

An ion exchange softener can treat a total of 820,000 gallons of water before regeneration of the resin is required. If the water is to be treated at a rate of 32,000 gph, how many hours of operation are there until regeneration is required?

*Solution*

Again referring to Equation 21.19:

$$\text{Operating time (hr)} = \frac{820,000 \text{ gal}}{32,000 \text{ gph}}$$

$$= 25.6 \text{ hr of operation before regeneration}$$

### SALT AND BRINE REQUIRED FOR REGENERATION

When calcium and magnesium ions replace the sodium ions in the ion exchange resin, the resin can no longer remove the hardness ions from the water. When this occurs, pumping a concentrated solution (10 to 14% sodium chloride solution) on the resin will regenerate it. When the resin is completely recharged with sodium ions, it is ready for softening again. Typically, the salt dosage required to prepare the brine solution ranges from 5 to 15 lb of salt/cu ft of resin. Equation 21.20 is used to calculate the salt required (pounds, lb) and Equation 21.21 is used to calculate brine (gallons):

$$\text{Salt required (lb)} = \text{Salt required (lb/kgrains removed)} \times \text{hardness removed (kgrains)} \tag{20.20}$$

$$\text{Brine (gal)} = \frac{\text{salt required (lb)}}{\text{brine solution (lb salt/gal brine)}} \tag{21.21}$$

To determine the brine solution (the lb salt per gal brine factor used in Equation 21.21), we must refer to the salt solutions table below:

**Salt Solutions Table**

| NaCl (%) | NaCl (lb/gal) | NaCl/cu ft (lb) |
|---|---|---|
| 10 | 0.874 | 6.69 |
| 11 | 0.990 | 7.41 |
| 12 | 1.09 | 8.14 |
| 13 | 1.19 | 8.83 |
| 14 | 1.29 | 9.63 |
| 15 | 1.39 | 10.4 |

### Example 21.28

*Problem*

An ion-exchange softener removes 1,310,000 grains hardness from the water before the resin must be regenerated. If 0.3 lb salt is required for each kilograin removed, how many pounds of salt will be required for preparing the brine to be used in resin regeneration?

*Solution*

$$\begin{aligned}\text{Salt required (lb)} &= \text{Salt required (lb/1000 grains)} \times \text{hardness removed (kg)}\\ &= 0.3 \text{ lb salt/kilograins removed} \times 1310 \text{ kilograins}\\ &= 393 \text{ lb}\end{aligned}$$

### Example 21.29

*Problem*

A total of 430 lb of salt is required to regenerate an ion exchange softener. If the brine solution is to be a 12% brine solution, how many gallons of brine will be required? (See Salt Solutions table to determine the lb salt/gal brine for a 12% brine solution.)

*Solution*

$$\begin{aligned}\text{Brine (gal)} &= \frac{\text{salt required (lb)}}{\text{brine solution (lb salt/gal brine)}}\\ &= \frac{430 \text{ lb salt}}{1.09 \text{ lb salt/gal brine}}\\ &= 394 \text{ gal of 12\% brine}\end{aligned}$$

Thus, 430 lb salt to make up a total of 394 gallons of brine will result in the desired 12% brine solution.

# Part III

## Wastewater Math Concepts

# 22 Preliminary Treatment Calculations

## TOPICS



The initial stage of treatment in the wastewater treatment process (following collection and influent pumping) is *preliminary treatment.* Process selection normally is based upon the expected characteristics of the influent flow. Raw influent entering the treatment plant may contain many kinds of materials (trash), and preliminary treatment protects downstream plant equipment by removing these materials, which could cause clogs, jams, or excessive wear in plant machinery. In addition, the removal of various materials at the beginning of the treatment train saves valuable space within the treatment plant.

Two of the processes used in preliminary treatment include screening and grit removal; however, preliminary treatment may also include other processes, each designed to remove a specific type of material that presents a potential problem for downstream unit treatment processes. These processes include shredding, flow measurement, preaeration, chemical addition, and flow equalization. Except in extreme cases, plant design will not include all of these items. In this chapter, we focus on and describe typical calculations used in two of these processes: screening and grit removal.

## SCREENING

*Screening* removes large solids, such as rags, cans, rocks, branches, leaves, and roots, from the flow before the flow moves on to downstream processes.

### Screening Removal Calculations

Wastewater operators responsible for screenings disposal are typically required to keep a record of the amount of screenings removed from the flow. To keep and maintain accurate screening records, the volume of screenings withdrawn must be determined. Two methods are commonly used to calculate the volume of screenings withdrawn:

$$\text{Screenings removed (cu ft/day)} = \frac{\text{screenings (cu ft)}}{\text{days}} \tag{22.1}$$

$$\text{Screenings removed (cu ft/MG)} = \frac{\text{screenings (cu ft)}}{\text{flow (MG)}} \tag{22.2}$$

### Example 22.1

*Problem*

A total of 65 gallons of screenings is removed from the wastewater flow during a 24-hour period. What is the screening removal reported as cubic feet per day (cu/ft/day)?

*Solution*

First, convert gallon screenings to ft$^3$

$$\frac{65 \text{ gal}}{7.48 \text{ gal/cu ft}} = 8.7 \text{ cu ft screenings}$$

Next, calculate screenings removed as cu ft/day:

$$\text{Screenings removed (cu ft/day)} = \frac{8.7 \text{ cu ft}}{1 \text{ day}} = 8.7 \text{ cu ft/day}$$

### Example 22.2

*Problem*

During 1 week, a total of 310 gallons of screenings was removed from wastewater screens. What is the average removal in cu ft/day?

*Solution*

First, gallon screenings must be converted to cu ft screenings:

$$\frac{310 \text{ gal}}{748 \text{ gal/cu ft}} = 41.4 \text{ cu ft screenings}$$

Next, we calculate the screening removal:

$$\text{Screenings removed (cu ft/day)} = \frac{41.4 \text{ cu ft}}{7 \text{ days}} = 5.9 \text{ cu ft/day}$$

## Screening Pit Capacity Calculations

Recall that detention time may be considered the time required for flow to pass through a basin or tank or the time required to fill a basin or tank at a given flow rate. In screening pit capacity problems, the time required to fill a screening pit is calculated. The equation used in screening pit capacity problems is given below:

$$\text{Screening pit fill time (day)} = \frac{\text{volume of pit (cu ft)}}{\text{screening removed (cu ft/day)}} \tag{22.3}$$

### Example 22.3

*Problem*

A screening pit has a capacity of 500 cu ft. (The pit is actually larger than 500 cu ft to accommodate soil for covering.) If an average of 3.4 cu ft of screenings are removed daily from the wastewater flow, in how many days will the pit be full? See Figure 22.1.

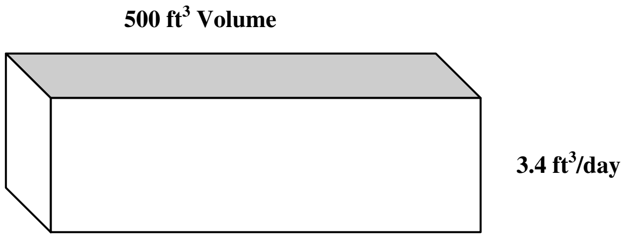


**FIGURE 22.1** Screenings pit. Refers to Example 22.3.

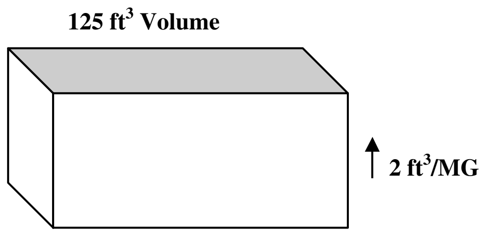


**FIGURE 22.2** Screenings pit. Refers to Example 22.4.

*Solution*

Referring to Equation 22.3:

$$\text{Screening pit fill time (day)} = \frac{500 \text{ cu ft}}{3.4 \text{ cu ft/day}}$$

$$= 147.1 \text{ days}$$

### Example 22.4

*Problem*

A plant has been averaging a screening removal of 2 cu ft/MG. If the average daily flow is 1.8 MGD, how many days will it take to fill the pit with an available capacity of 125 cu ft? See Figure 22.2.

*Solution*

The filling rate must first be expressed as cu ft/day:

$$\frac{2 \text{ cu ft} \times 1.8 \text{ MGD}}{\text{MG}} = 3.6 \text{ cu ft/day}$$

$$\text{Screening pit fill time (days)} = \frac{125 \text{ cu ft}}{3.6 \text{ cu ft/day}}$$

$$= 34.7 \text{ days}$$

### Example 22.5

*Problem*

A screening pit has a capacity of 12 cu yd available for screenings. If the plant removes an average of 2.4 cu ft of screenings per day, in how many days will the pit be filled? See Figure 22.3.

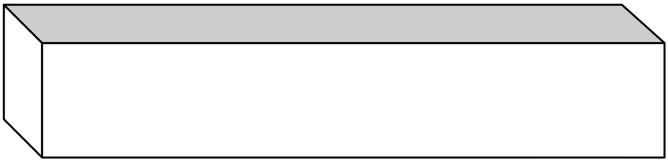


**FIGURE 22.3** Screenings pit. Refers to Example 22.5.

*Solution*

Because the filling rate is expressed as cu ft/day, the volume must be expressed as cu ft:

$$12 \text{ cu yd} \times 27 \text{ cu ft/cu yd} = 324 \text{ cu ft}$$

Now calculate fill time using Equation 22.3:

$$\text{Screening pit fill time (day)} = \frac{324 \text{ cu ft}}{2.4 \text{ cu ft/day}}$$

$$= 135 \text{ days}$$

## GRIT REMOVAL

The purpose of *grit removal* is to remove inorganic solids (sand, gravel, clay, egg shells, coffee grounds, metal filings, seeds, and other similar materials) that could cause excessive mechanical wear. Several processes or devices are used for grit removal, all based on the fact that grit is heavier than the organic solids, which should be kept in suspension for treatment in following unit processes. Grit removal may be accomplished in grit chambers or by the centrifugal separation of biosolids. Processes use gravity/velocity, aeration, or centrifugal force to separate the solids from the wastewater.

### GRIT REMOVAL CALCULATIONS

Wastewater systems typically average 1 to 15 cubic feet of grit per million gallons of flow (sanitary systems, 1 to 4 cu ft/million gal; combined wastewater systems, from 4 to 15 cu ft/million gals of flow), with higher ranges during storm events. Generally, grit is disposed of in sanitary landfills, so, for planning purposes, operators must keep accurate records of grit removal. Most often, the data are reported as cubic feet of grit removed per million gallons for flow:

$$\text{Grit removed (cu ft/MG)} = \frac{\text{grit volume (cu ft)}}{\text{flow (MG)}} \tag{22.4}$$

Over a given period, the average grit removal rate at a plant (at least a seasonal average) can be determined and used for planning purposes. Typically, grit removal is calculated as cubic yards, because excavation is normally expressed in terms of cubic yards:

$$\text{Cubic yards grit} = \frac{\text{total grit (cu ft)}}{27 \text{ cu ft/cu yd}} \tag{22.5}$$

### Example 22.6

*Problem*

A treatment plant removes 10 cu ft of grit in 1 day. How many $ft^3$ of grit are removed per million gallons if the plant flow is 9 MGD?

*Solution*

Referring to Equation 22.4:

$$\text{Grit removed } (\text{cu ft/MG}) = \frac{10 \text{ cu ft}}{9 \text{ MG}}$$

$$= 1.1 \text{ cu ft/MG}$$

### Example 22.7

*Problem*

The total daily grit removed for a plant is 250 gallons. If the plant flow is 12.2 MGD, how many cubic feet of grit are removed per MG flow?

*Solution*

First, convert gallon grit removed to cu ft:

$$\frac{250 \text{ gal}}{7.48 \text{ gal/cu ft}} = 33 \text{ cu ft}$$

Next, complete the calculation of cu ft/MG:

$$\text{Grit removed } (\text{cu ft/MG}) = \frac{33 \text{ cu ft}}{12.2 \text{ MGD}}$$

$$= 2.7 \text{ cu ft/MGD}$$

### Example 22.8

*Problem*

The monthly average grit removal is 2.5 cu ft/MG. If the monthly average flow is 2,500,000 gpd, how many cu yards must be available for grit disposal if the disposal pit is to have a 90-day capacity?

*Solution*

First, calculate the grit generated each day:

$$\frac{2.5 \text{ cu ft}}{\text{MG}} \times 2.5 \text{ MGD} = 6.25 \text{ cu ft each day}$$

The cu ft grit generated for 90 days would be:

$$\frac{6.25 \text{ cu ft}}{\text{day}} \times 90 \text{ days} = 562.5 \text{ cu ft}$$

Convert cu ft to cu yd grit:

$$\frac{562.5 \text{ cu ft}}{27 \text{ cu ft/cu yd}} = 21 \text{ cu yd}$$

### Grit Channel Velocity Calculation

The optimum velocity in sewers is approximately 2 fps at peak flow, because this velocity normally prevents solids from settling from the lines; however, when the flow reaches the grit channel, the velocity should decrease to about 1 fps to permit the heavy inorganic solids to settle. In the example calculations that follow, we describe how the velocity of the flow in a channel can be determined by the float and stopwatch method and by channel dimensions.

#### Example 22.9 (Velocity by Float and Stopwatch)

$$\text{Velocity (ft/second)} = \frac{\text{distance traveled (ft)}}{\text{time required (seconds)}} \tag{22.6}$$

*Problem*

It takes a float 30 seconds to travel 37 feet in a grit channel. What is the velocity of the flow in the channel?

*Solution*

$$\text{Velocity (fps)} = \frac{37 \text{ ft}}{30 \text{ sec}} = 1.2 \text{ fps}$$

#### Example 22.10 (Velocity by Flow and Channel Dimensions)

This calculation can be used for a single channel or tank or for multiple channels or tanks with the same dimensions and equal flow. If the flow through each unit of the unit dimensions is unequal, the velocity for each channel or tank must be computed individually.

$$\text{Velocity (fps)} = \frac{\text{flow (MGD)} \times 1.55 \text{ cfs/MGD}}{\text{No. channels in service} \times \text{channel width (ft)} \times \text{water depth (ft)}} \tag{22.7}$$

*Problem*

A plant is currently using two grit channels. Each channel is 3 ft wide and has a water depth of 1.3 ft. What is the velocity when the influent flow rate is 4.0 MGD?

*Solution*

$$\text{Velocity (fps)} = \frac{4.0 \text{ MGD} \times 1.55 \text{ cfs/MGD}}{2 \text{ channels} \times 3 \text{ ft} \times 1.3 \text{ ft}}$$

$$= \frac{6.2 \text{ cfs}}{7.8 \text{ ft}^2} = 0.79 \text{ fps}$$

✔ **Key Point:** Because 0.79 is within the 0.7 to 1.4 level, the operator of this unit would not make any adjustments.

✔ **Key Point:** The channel dimensions must always be in feet. Convert inches to feet by dividing by 12 inches per foot.

### Example 22.11 (Required Settling Time)

This calculation can be used to determine the time required for a particle to travel from the surface of the liquid to the bottom at a given settling velocity. To compute the settling time, settling velocity in ft/sec must be provided or determined by experiment in a laboratory.

$$\text{Settling time (seconds)} = \frac{\text{liquid depth in ft}}{\text{settling velocity (fps)}} \tag{22.8}$$

*Problem*

A plant's grit channel is designed to remove sand, which has a settling velocity of 0.080 fps. The channel is currently operating at a depth of 2.3 ft. How many seconds will it take for a sand particle to reach the channel bottom?

*Solution*

$$\text{Settling time (sec)} = \frac{2.3\text{ ft}}{0.080\text{ fps}} = 28.7\text{ sec}$$

### Example 22.12 (Required Channel Length)

This calculation can be used to determine the length of channel required to remove an object with a specified settling velocity.

$$\text{Required channel length} = \frac{\text{channel depth (ft)} \times \text{flow velocity (fps)}}{0.080\text{ fps}} \tag{22.9}$$

*Problem*

The grit channel of a plant is designed to remove sand, which has a settling velocity of 0.080 fps. The channel is currently operating at a depth of 3 ft. The calculated velocity of flow through the channel is 0.85 fps. The channel is 36 ft long. Is the channel long enough to remove the desired sand particle size?

*Solution*

Referring to Equation 22.9:

$$\text{Required channel length} = \frac{3\text{ ft} \times 0.85\text{ fps}}{0.080\text{ fps}} = 31.6\text{ ft}$$

Yes, the channel is long enough to ensure that all the sand will be removed.

# 23 Primary Treatment Calculations

## TOPICS



*Primary treatment* (primary sedimentation or clarification) should remove both settleable organic and floatable solids. Poor solids removal during this step of treatment may cause organic overloading of the biological treatment processes following primary treatment. Normally, each primary clarification unit can be expected to remove 90 to 95% of settleable solids, 40 to 60% of the total suspended solids, and 25 to 35% of biological oxygen demand (BOD).

## PROCESS CONTROL CALCULATIONS

As with many other wastewater treatment plant unit processes, several process control calculations may be helpful in evaluating the performance of the primary treatment process. Process control calculations are used in the sedimentation process to determine:

- Percent removal
- Hydraulic detention time
- Surface loading rate (surface settling rate)
- Weir overflow rate (weir loading rate)
- Biosolids pumping
- Percent total solids (% TS)
- BOD and SS removed (lb/day)

In the following sections, we take a closer look at a few of these process control calculations and example problems.

> ✓ **Key Point:** The calculations presented in the following sections allow us to determine values for each function performed. Again, keep in mind that an optimally operated primary clarifier should have values in an expected range. Recall that the expected ranges of percent removal for a primary clarifier are:

- Settleable solids, 90–95%
- Suspended solids, 40–60%
- BOD, 25–35%

The expected range of hydraulic detention time for a primary clarifier is 1 to 3 hours. The expected range of surface loading/settling rate for a primary clarifier is 600 to 1200 gpd/sq ft) (ballpark estimate). The expected range of weir overflow rate for a primary clarifier is 10,000 to 20,000 gpd/ft.

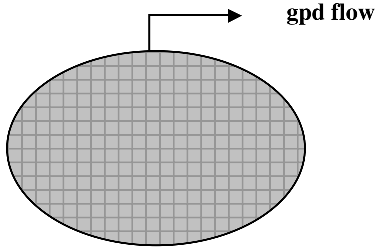


**FIGURE 23.1** Primary clarifier.

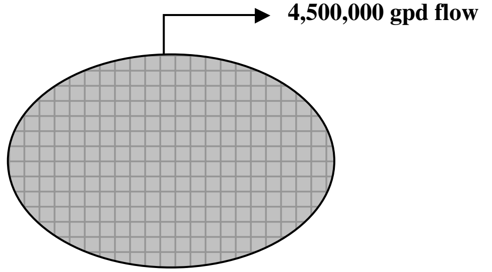


**FIGURE 23.2** Refers to Example 23.1.

### Surface Loading Rate (Surface Settling Rate/Surface Overflow Rate)

*Surface loading rate* is the number of gallons of wastewater passing over 1 square foot of tank per day (see Figure 23.1). This figure can be used to compare actual conditions with design. Plant designs generally use a surface-loading rate of 300 to 1200 gal/day/sq ft.

$$\text{Surface loading rate}\left(\text{gpd/ft}^2\right) = \frac{\text{gal/day}}{\text{surface tank area}\left(\text{ft}^2\right)} \tag{23.1}$$

## Example 23.1

*Problem*

A circular settling tank has a diameter of 120 feet. If the flow to the unit is 4.5 MGD, what is the surface loading rate (in gal/day/ft$^2$) (see Figure 23.2)?

*Solution*

$$\text{Surface loading rate} = \frac{4.5\text{ MGD} \times 1{,}000{,}000\text{ gal/MGD}}{0.785 \times 120\text{ ft} \times 120\text{ ft}} = 398\text{ gpd/ft}^2$$

## Example 23.2

*Problem*

A circular clarifier has a diameter of 50 ft. If the primary effluent flow is 2,150,000 gpd, what is the surface overflow rate (in gpd/sq ft)?

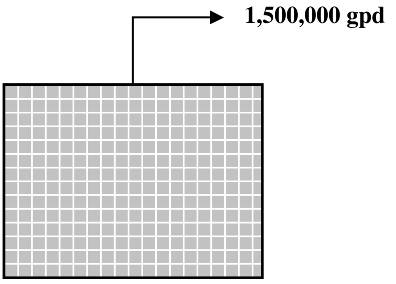


**FIGURE 23.3** Refers to Eample 23.3.

*Solution*

✓ **Key Point:** Remember that area = 0.785 × 50 ft × 50 ft.

$$\text{Surface overflow rate} = \frac{\text{flow (gpd)}}{\text{area (sq ft)}}$$

$$= \frac{2{,}150{,}000}{0.785 \times 50 \text{ ft} \times 50 \text{ ft}} = 1096 \text{ gpd/sq ft}$$

### Example 23.3

*Problem*

A sedimentation basin that is 90 ft by 20 ft receives a flow of 1.5 MGD. What is the surface overflow rate (in gpd/sq ft) (see Figure 23.3)?

$$\text{Surface overflow rate} = \frac{\text{flow (gpd)}}{\text{area (sq ft)}}$$

$$= \frac{1{,}500{,}000 \text{ gpd}}{90 \text{ ft} \times 20 \text{ ft}}$$

$$= 833 \text{ gpd/sq ft}$$

## Weir Overflow Rate (Weir Loading Rate)

A weir is a device used to measure wastewater flow (see Figure 23.4). *Weir overflow rate* (or *weir loading rate*) is the amount of water leaving the settling tank per linear foot of water. The result of this calculation can be compared with design. Normally, weir overflow rates of 10,000 to 20,000 gal/day/ft are used in the design of a settling tank.

$$\text{Weir overflow rate (gpd/ft)} = \frac{\text{flow (gpd)}}{\text{weir length (ft)}} \tag{23.2}$$

✓ **Key Point:** To calculate weir circumference, use total feet of weir = 3.14 × weir diameter (ft).

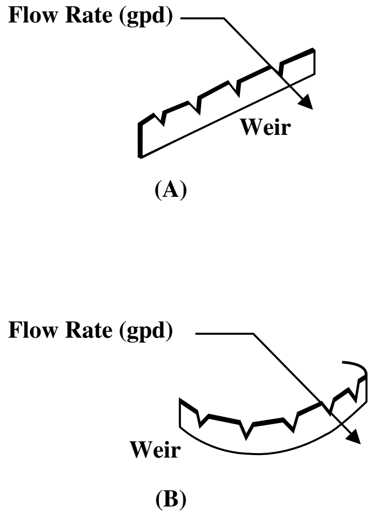


**FIGURE 23.4** (a) Weir overflow for rectangular clarifier, (b) weir overflow for circular clarifier.

### Example 23.4

*Problem*

A circular settling tank is 80 feet in diameter and has a weir along its circumference. The effluent flow rate is 2.75 MGD. What is the weir overflow rate in gallons per day per foot?

*Solution*

$$\text{Weir overflow rate } (\text{gpd/ft}) = \frac{2.75 \text{ MGD} \times 1{,}000{,}000 \text{ gal}}{3.14 \times 80 \text{ ft}} = 10{,}947 \text{ gal/day/ft}$$

**Key Point:** Notice that 10,947 gal/day/ft is above the recommended minimum of 10,000.

### Example 23.5

*Problem*

A rectangular clarifier has a total of 70 ft of weir. What is the weir overflow rate (in gpd/ft) when the flow is 1,055,000 gpd?

*Solution*

$$\text{Weir overflow rate} = \frac{1{,}055{,}000 \text{ gpd}}{70 \text{ ft}}$$

$$= 15{,}071 \text{ gpd}$$

## Biosolids Pumping

Determination of *biosolids pumping* (the quantity of solids and volatile solids removed from the sedimentation tank) provides accurate information needed for process control of the sedimentation process:

$$\text{Solids pumped} = \text{Pump rate (gpm)} \times \text{pump time (min/day)} \times 8.34 \text{ lb/gal} \times \% \text{ solids} \quad (23.3)$$

$$\text{Volatile solids (lb/day)} = \text{Pump rate} \times \text{pump time} \times 8.34 \times \% \text{ solids} \times \% \text{ volatile matter} \quad (23.4)$$

### Example 23.6

*Problem*

A biosolids pump operates 30 minutes per hour. The pump delivers 25 gal/min of biosolids. Laboratory tests indicate that the biosolids are 5.3% solids and 68% volatile matter. How many pounds of volatile matter are transferred from the settling tank to the digester? Assume a 24-hour period.

*Solution*

Pump time = 30 min/hr
Pump rate = 25 gpm
% solids = 5.3%
% volatile matter = 68%

$$\text{Volatile solids (lb/day)} = 25 \text{ gpm} \times (30 \text{ min/hr} \times 24 \text{ hr/day}) \times 8.34 \text{ lb/gal} \times 0.053 \times 0.68$$

$$= 5410 \text{ lb/day}$$

## Percent Total Solids (%TS)

*Problem*

A settling tank biosolids sample is tested for solids. The sample and dish weigh 73.79 g. The dish alone weighs 21.4 g. After drying, the dish with dry solids weighs 22.4 g. What is the percent total solids (%TS) of the sample?

*Solution*

| | | | |
|---|---|---|---|
| Sample + dish | 73.79 g | Dish + dry solids | 22.4 g |
| Dish alone | –21.4 g | Dish alone | –21.4 g |
| Difference | 52.39 g | Difference | 1.0 g |

$$\frac{1.0 \text{ g}}{52.39 \text{ g}} \times 100\% = 1.9\%$$

## BOD and SS Removed (lb/d)

To calculate the pounds of BOD or suspended solids (SS) removed each day, we need to know the mg/L BOD or suspended solids removed and the plant flow. Then, we can use the mg/L to lb/d equation.

$$\text{SS removed} = \text{mg/L} \times \text{MGD} \times 8.34 \text{ lb/gal} \tag{23.5}$$

### Example 23.7

*Problem*

If 120 mg/L suspended solids are removed by a primary clarifier, how many lb/day suspended solids are removed when the flow is 6,250,000 gpd?

*Solution*

$$\text{SS removed} = 120 \text{ mg/L} \times 6.25 \text{ MGD} \times 8.34 \text{ lb/gal} = 6255 \text{ lb/day}$$

**Example 23.8**

*Problem*

The flow to a secondary clarifier is 1.6 MGD. If the influent BOD concentration is 200 mg/L and the effluent BOD concentration is 70 mg/L, how many pounds of BOD are removed daily?

*Solution*

$$\text{BOD removed (lb/day)} = 200 \text{ mg/L} - 70 \text{ mg/L} = 130 \text{ mg/L}$$

After calculating mg/L BOD removed, calculate lb/day BOD removed:

$$\text{BOD removed (lb/day)} = 130 \text{ mg/L} \times 1.6 \text{ MGD} \times 8.34 \text{ lb/gal} = 1735 \text{ lb/day}$$

# 24 Trickling Filter Calculations

## TOPICS



The *trickling filter process* (see Figure 24.1) is one of the oldest forms of dependable biological treatment for wastewater. By its very nature, the trickling filter has advantages over other unit processes. For example, it is a very economical and dependable process for treatment of wastewater prior to discharge. Capable of withstanding periodic shock loading, process energy demands are low because aeration is a natural process. As shown in Figure 24.2, the trickling filter operation involves spraying wastewater over a solid media such as rock, plastic, or redwood slats (or laths). As the wastewater trickles over the surface of the media, a growth of microorganisms (bacteria, protozoa, fungi, algae, helminths or worms, and larvae) develops. This growth is visible as a shiny slime very similar to the slime found on rocks in a stream. As wastewater passes over this slime, the slime adsorbs the organic (food) matter. This organic matter is used for food by the microorganisms. At the same time, air moving through the open spaces in the filter transfers oxygen to the wastewater. This oxygen is then transferred to the slime to keep the outer layer aerobic. As the microorganisms use the food and oxygen, they produce more organisms, carbon dioxide, sulfates, nitrates, and other stable byproducts; these materials are then discarded from the slime back into the wastewater flow and are carried out of the filter.

## TRICKLING FILTER PROCESS CALCULATIONS

Several calculations are useful in the operation of trickling filters: these include hydraulic loading, organic loading, and biochemical oxygen demand (BOD) and suspended solids (SS) removal. Each type of trickling filter is designed to operate with specific loading levels. These levels very greatly depending on the filter classification. To operate the filter properly, filter loading must be within the specified levels. The three main loading parameters for the trickling filter are hydraulic loading, organic loading, and recirculation ratio.

### Hydraulic Loading Rate

Calculating the *hydraulic loading rate* is important to accounting for both the primary effluent as well as the recirculated trickling filter effluent. These quantities are combined before being applied to the filter surface. The hydraulic loading rate is calculated based on filter surface area. The normal hydraulic loading rate ranges for standard rate and high rate trickling filters are:

- Standard rate, 25 to 100 gpd/sq ft or 1 to 40 MGD/acre
- High rate, 100 to 1000 gpd/sq ft or 4 to 40 MGD/acre

**Key Point:** If the hydraulic loading rate for a particular trickling filter is too low, septic conditions will begin to develop.

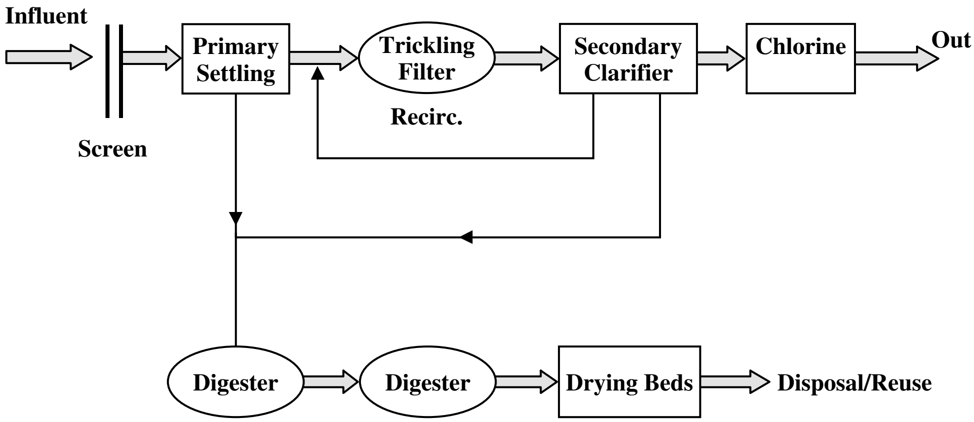


**FIGURE 24.1** Trickling filter system.

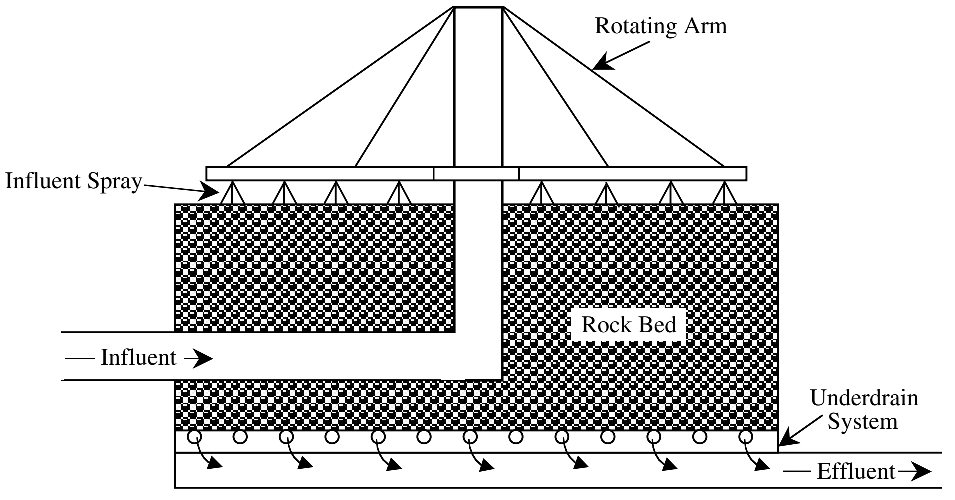


**FIGURE 24.2** Cross-section of a trickling filter.

## Example 24.1

### *Problem*

A trickling filter that is 80 ft in diameter is operated with a primary effluent of 0.588 MGD and a recirculated effluent flow rate of 0.660 MGD. Calculate the hydraulic loading rate on the filter (in gpd/$ft^2$).

### *Solution*

The primary effluent and recirculated trickling filter effluent are applied together across the surface of the filter; therefore, 0.588 MGD + 0.660 MGD = 1.248 MGD = 1,248,000 gpd.

$$\begin{aligned}\text{Circular surface area} &= 0.785 \times (\text{diameter})^2 \\ &= 0.785 \times (80\ \text{ft})^2 \\ &= 5024\ \text{ft}^2\end{aligned}$$

$$\frac{1{,}248{,}000\ \text{gpd}}{5024\ \text{ft}^2} = 248.4\ \text{gpd/ft}^2$$

### Example 24.2

*Problem*

A trickling filter that is 80 ft in diameter treats a primary effluent flow of 550,000 gpd. If the recirculated flow to the clarifier is 0.2 MGD, what is the hydraulic loading on the trickling filter?

*Solution*

$$\text{Hydraulic loading rate} = \frac{\text{total flow (gpd)}}{\text{area (sq ft)}}$$

$$= \frac{750{,}000 \text{ gpd total flow}}{0.785 \times 80 \text{ ft} \times 80 \text{ ft}}$$

$$= 149 \text{ gpd/sq ft}$$

### Example 24.3

*Problem*

A high-rate trickling filter receives a daily flow of 1.8 MGD. What is the dynamic loading rate in MGD/acre if the filter is 90 ft in diameter and 5 ft deep?

*Solution*

$$(0.785 \times 90 \text{ ft} \times 90 \text{ ft}) = 6359 \text{ sq ft}$$

$$\frac{6359 \text{ sq ft}}{43{,}560 \text{ sq ft/ac}} = 0.146 \text{ acres}$$

$$\text{Hydraulic loading rate} = \frac{1.8 \text{ MGD}}{0.146 \text{ acres}} = 12.3 \text{ MGD/ac}$$

**Key Point:** When hydraulic loading rate is expressed as MGD per acre, this is still an expression of gallon flow over surface area of trickling filter.

## Organic Loading Rate

Trickling filters are sometimes classified by the *organic loading rate* applied. The organic loading rate is expressed as a certain amount of BOD applied to a certain volume of media. In other words, the organic loading is defined as the pounds of BOD or chemical oxygen demand (COD) applied per day per 1000 cubic feet of media — a measure of the amount of food being applied to the filter slime. To calculate the organic loading on the trickling filter, two things must be known: the pounds of BOD or COD being applied to the filter media per day and the volume of the filter media in units of 1000 cubic feet. The BOD and COD contribution of the recirculated flow is not included in the organic loading.

### Example 24.4

*Problem*

A trickling filter that is 60 ft in diameter receives a primary effluent flow rate of 0.440 MGD. Calculate the organic loading rate in units of pounds of BOD applied per day per 1000 $ft^3$ of media volume. The primary effluent BOD concentration is 80 mg/L. The media depth is 9 ft.

*Solution*

$$0.440 \text{ MGD} \times 80 \text{ mg/L} \times 8.34 \text{ lb/gal} = 293.6 \text{ lb of BOD applied/d}$$

$$\text{Surface area} = 0.785 \times (60)^2 = 2826 \text{ ft}^2$$

$$\text{Area} \times \text{depth} \times \text{volume} = \text{cu ft}$$

$$2826 \text{ ft}^2 \times 9 \text{ ft} = 25{,}434 \text{ cu ft (TF volume)}$$

✔ **Key Point:** To determine the pounds of BOD per 1000 $ft^3$ in a volume of thousands of cubic feet, we must set up the equation as shown below:

$$\frac{293.6 \text{ lb BOD/d}}{25{,}434 \text{ ft}^3} \times \frac{1000}{1000}$$

Regrouping the numbers and the units together:

$$\frac{293.6 \text{ lb BOD/d} \times 1000}{25{,}434 \text{ ft}^3} \times \frac{\text{lb BOD/d}}{1000 \text{ ft}^3} = 11.5 \times \frac{\text{lb BOD/d}}{1000 \text{ ft}^3}$$

## BOD and SS Removed

To calculate the pounds of BOD or suspended solids removed each day, we need to know the mg/L BOD and SS removed and the plant flow.

### Example 24.5

*Problem*

If 120 mg/L suspended solids are removed by a trickling filter, how many lb/day of suspended solids are removed when the flow is 4.0 MGD?

*Solution*

$$\text{mg/L} \times \text{MGD flow} \times 8.34 \text{ lb/gal} = \text{lb/day}$$

$$120 \text{ mg/L} \times 4.0 \text{ MGD} \times 8.34 \text{ lb/gal} = 4003 \text{ lb SS/day}$$

### Example 24.6

*Problem*

The 3,500,000-gpd influent flow to a trickling filter has a BOD content of 185 mg/L. If the trickling filter effluent has a BOD content of 66 mg/L, how many pounds of BOD are removed daily?

*Solution*

$$\text{mg/L} \times \text{MGD flow} \times 8.34 \text{ lb/gal} = \text{lb/day removed}$$

$$185 \text{ mg/L} - 66 \text{ mg/L} = 119 \text{ mg/L}$$

$$119 \text{ mg/L} \times 3.5 \text{ MGD} \times 8.34 \text{ lb/gal} = 3474 \text{ lb/day removed}$$

### Recirculation Ratio

*Recirculation* in trickling filters involves the return of filter effluent back to the head of the trickling filter. It can level flow variations and assist in solving operational problems, such as ponding, filter flies, and odors. The operator must check the rate of recirculation to ensure that it is within design specifications. Rates above design specifications indicate hydraulic overloading; rates under design specifications indicate hydraulic underloading. The *trickling filter recirculation ratio* is the ratio of the recirculated trickling filter flow to the primary effluent flow. The trickling filter recirculation ratio may range from 0.5:1 (.5) to 5:1 (5); however, the ratio is often found to be 1:1 or 2:1.

$$\text{Recirculation ratio} = \frac{\text{recirculated flow (MGD)}}{\text{primary effluent flow (MGD)}} \tag{24.1}$$

#### Example 24.7

*Problem*

A treatment plant receives a flow of 3.2 MGD. If the trickling filter effluent is recirculated at the rate of 4.5 MGD, what is the recirculation ratio?

*Solution*

Referring to Equation 24.1:

$$\text{Recirculation ratio} = \frac{4.5\text{ MGD}}{3.2\text{ MGD}}$$

$$= 1.4$$

#### Example 24.8

*Problem*

A trickling filter receives a primary effluent flow of 5 MGD. If the recirculated flow is 4.6 MGD, what is the recirculation ratio?

*Solution*

Again referring to Equation 24.1:

$$\text{Recirculation ratio} = \frac{4.6\text{ MGD}}{5\text{ MGD}}$$

$$= 0.92$$

# 25 Rotating Biological Contactors (RBCs)

## TOPICS



The *rotating biological contactor* (RBC) is a variation of the attached growth idea provided by the trickling filter (see Figure 25.1). Although still relying on microorganisms that grow on the surface of a medium, the RBC is a *fixed-film* biological treatment device. The basic biological process, however, is similar to that occurring in trickling filters. An RBC consists of a series of closely spaced (mounted side by side), circular, plastic, synthetic disks, typically about 11.5 ft in diameter (see Figure 25.2). Attached to a rotating horizontal shaft, approximately 40% of each disk is submersed in a tank that contains the wastewater to be treated. As the RBC rotates, the attached biomass film (zoogleal slime) that grows on the surface of the disks moves into and out of the wastewater. While they are submerged in the wastewater, the microorganisms absorb organics; while they are rotated out of the wastewater, they are supplied with needed oxygen for aerobic decomposition. As the zoogleal slime re-enters the wastewater, excess solids and waste products are stripped off the media as *sloughings*. These sloughings are transported with the wastewater flow to a settling tank for removal.

## RBC PROCESS CONTROL CALCULATIONS

Several process control calculations may be useful in the operation of an RBC, including soluble BOD, total media area, organic loading rate, and hydraulic loading. Settling tank calculations and biosolids pumping calculations may be helpful for evaluation and control of the settling tank following the RBC.

### HYDRAULIC LOADING RATE

The manufacturer normally specifies the RBC media surface area, and the hydraulic loading rate is based on the media surface area, usually in square feet ($ft^2$). Hydraulic loading is expressed in terms of gallons of flow per day per square foot of media. This calculation can be helpful in evaluating the current operating status of the RBC. Comparison with design specifications can determine if the unit is hydraulically over- or underloaded. Hydraulic loading on an RBC can range from 1 to 3 gpd/$ft^2$.

#### Example 25.1

*Problem*

An RBC treats a primary effluent flow rate of 0.244 MGD. What is the hydraulic loading rate in gpd/$ft^2$ if the media surface area is 92,600 $ft^2$?

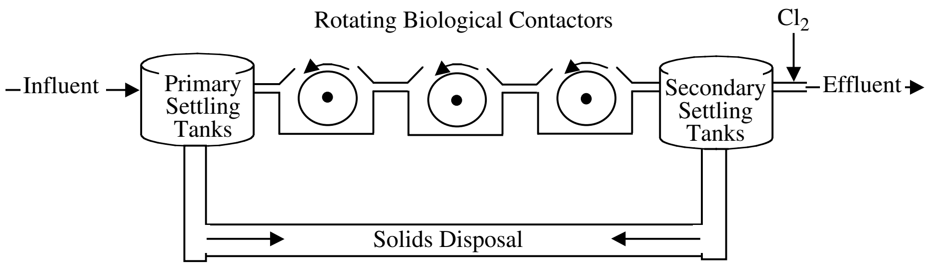


**FIGURE 25.1** Rotating biological contactor (RBC) treatment system.

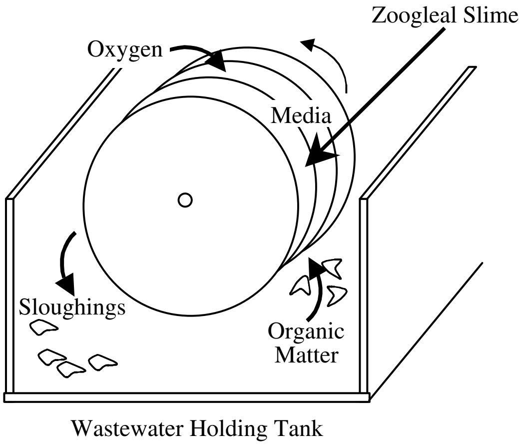


**FIGURE 25.2** Rotating biological contactor (RBC) cross-section and treatment system.

*Solution*

$$\frac{244{,}000 \text{ gpd}}{92{,}000 \text{ ft}^2} = 2.63 \text{ gpd/ft}^2$$

## Example 25.2

*Problem*

An RBC treats a flow of 3.5 MGD. The manufacturer's data indicate a media surface area of 750,000 sq ft. What is the hydraulic loading rate on the RBC?

*Solution*

$$\text{Hydraulic loading rate} = \frac{\text{flow (gpd)}}{\text{media area (sq ft)}}$$

$$= \frac{3{,}500{,}000 \text{ gpd}}{750{,}000 \text{ sq ft}} = 4.7 \text{ sq ft}$$

## Example 25.3

*Problem*

A rotating biological contactor treats a primary effluent flow of 1,350,000 gpd. The manufacturer's data indicate that the media surface area is 600,000 sq ft. What is the hydraulic loading rate on the filter?

$$\text{Hydraulic loading rate} = \frac{\text{flow (gpd)}}{\text{area (sq ft)}}$$

$$= \frac{1{,}350{,}000 \text{ gpd}}{600{,}000 \text{ sq ft}} = 2.3 \text{ sq ft}$$

## Soluble BOD

The *soluble BOD* concentration of the RBC influent can be determined experimentally in the laboratory, or it can be estimated using the suspended solids concentration and the *K* factor, which is used to approximate the BOD (particulate BOD) contributed by the suspended matter. The *K* factor must be provided or determined experimentally in the laboratory. The *K* factor for domestic wastes is normally in the range of 0.5 to 0.7.

$$\text{Soluble BOD}_5 = \text{Total BOD}_5 - (K \text{ factor} \times \text{total suspended solids}) \tag{25.1}$$

### Example 25.4

*Problem*

The suspended solids concentration of a wastewater is 250 mg/L. If the *K* value at the plant is 0.6, what is the estimated particulate BOD concentration of the wastewater?

*Solution*

✓ **Key Point:** A *K* value of 0.6 indicates that about 60% of the suspended solids are organic suspended solids (particulate BOD).

$$250 \text{ mg/L} \times 0.6 = 150 \text{ mg/L particulate BOD}$$

### Example 25.5

*Problem*

A rotating biological contactor receives a flow of 2.2 MGD with a BOD content of 170 mg/L and suspended solids (SS) concentration of 140 mg/L. If the *K* value is 0.7, how many pounds of soluble BOD enter the RBC daily?

*Solution*

$$\text{Total BOD} = \text{particulate BOD} + \text{soluble BOD}$$

$$170 \text{ mg/L} = (140 \text{ mg/L} \times 0.7) + x \text{ mg/L}$$

$$170 \text{ mg/L} = 98 \text{ mg/L} + x \text{ mg/L}$$

$$170 \text{ mg/L} - 98 \text{ mg/L} = x$$

$$x = 72 \text{ mg/L soluble BOD}$$

Now lb/day soluble BOD can be determined:

$$\text{Soluble BOD (mg/L)} \times \text{MGD Flow} \times 8.34 \text{ lb/gal} = \text{lb/day}$$

$$\text{Soluble BOD (lb/day)} = 72 \text{ mg/L x } 2.2 \text{ MGD} \times 8.34 \text{ lb/gal} = 1321 \text{ lb/day}$$

**Example 25.6**

*Problem*

The wastewater entering a rotating biological contactor has a BOD content of 210 mg/L. The suspended solids content is 240 mg/L. If the *K* value is 0.5, what is the estimated soluble BOD (mg/L) of the wastewater?

*Solution*

$$\text{Total BOD}\ (\text{mg/L}) = \text{particulate BOD}\ (\text{mg/L}) + \text{soluble BOD}\ (\text{mg/L})$$

$$\underset{\text{BOD}}{210\ \text{mg/L}} = (\underset{\text{SS}}{240\ \text{mg/L}} \times 0.5) + \underset{\text{Soluble BOD}}{x\ \text{mg/L}}$$

$$210\ \text{mg/L} = 120\ \text{mg/L} + \underset{\text{Soluble BOD}}{x\ \text{mg/L}}$$

$$210 - 120 = x$$

$$\text{Soluble BOD } 90\ \text{mg/L} = x$$

## Organic Loading Rate

The *organic loading rate* can be expressed as total BOD loading in pounds per day per 1000 square feet of media. The actual values can then be compared with plant design specifications to determine the current operating condition of the system.

$$\text{Organic loading rate} = \frac{\text{soluble BOD} \times \text{flow (MGD)} \times 8.34\ \text{lb/gal}}{\text{media area (1000 sq ft)}} \qquad (25.2)$$

**Example 25.7**

*Problem*

An RBC has a media surface area of 500,000 sq ft and receives a flow of 1,000,000 gpd. If the soluble BOD concentration of the primary effluent is 160 mg/L, what is the organic loading on the RBC in lb/day/1000 sq ft?

*Solution*

Referring to Equation 25.2,

$$\text{Organic loading rate} = \frac{(160\ \text{mg/L} \times 1.0\ \text{MGD} \times 8.34\ \text{lb/gal})}{500{,}000\ \text{sq ft}}$$

$$= \frac{2.7\ \text{lb/day soluble BOD}}{1000\ \text{sq ft}}$$

**Example 25.8**

*Problem*

The wastewater flow to an RBC is 3,000,000 gpd. The wastewater has a soluble BOD concentration of 120 mg/L. The RBC consists of six shafts (each 110,000 sq ft), with two shafts comprising the first stage of the system. What is the organic loading rate in lb/d/1000 sq ft on the first stage of the system?

*Solution*

Again referring to Equation 25.2:

$$\text{Organic loading rate} = \frac{(120 \text{ mg/L} \times 3.0 \text{ MGD} \times 8.34 \text{ lb/gal})}{220 \times 1000 \text{ sq ft}}$$

$$= 13.6 \text{ lb soluble BOD/day/1000 sq ft}$$

### Total Media Area

Several process control calculations for the RBC use the total surface area of all the stages within the train. As was the case with the soluble BOD calculation, plant design information or information supplied by the unit manufacturer must provide the individual stage areas (or the total train area), because physical determination of this would be extremely difficult.

$$\text{Total area} = \text{first stage area} + \text{second stage area} + \ldots + n\text{th stage area} \tag{25.3}$$

# 26 Activated Biosolids

## TOPICS



The *activated biosolids process* is a manmade process that mimics the natural self-purification process that takes place in steams. In essence, we can state that the activated biosolids treatment process is a "stream in a container." In wastewater treatment, activated biosolids processes are used for both secondary treatment and complete aerobic treatment without primary sedimentation. Activated biosolids refers to biological treatment systems that use a suspended growth of organisms to remove BOD and suspended solids.

The basic components of an activated biosolids sewage treatment system include an aeration tank and a secondary basin, settling basin, or clarifier (see Figure 26.1). Primary effluent is mixed with settled solids recycled from the secondary clarifier and this mixture is then introduced into the aeration tank. Compressed air is injected continuously into the mixture through porous diffusers located at the bottom of the tank, usually along one side.

Wastewater is fed continuously into an aerated tank, where the microorganisms metabolize and biologically flocculate the organics. Microorganisms (activated biosolids) are settled from the aerated mixed liquor under quiescent conditions in the final clarifier and are returned to the aeration tank. Left uncontrolled, the number of organisms would eventually become too great; therefore, some must be removed periodically (wasted). A portion of the concentrated solids from the bottom of the settling tank must be removed form the process (waste-activated sludge, or WAS). Clear supernatant from the final settling tank is the plant effluent.

## ACTIVATED BIOSOLIDS PROCESS CONTROL CALCULATIONS

As with other wastewater treatment unit processes, process control calculations are important tools used by operators to control and optimize process operations. In this chapter, we review many of the most frequently used activated biosolids process calculations.

### MOVING AVERAGES

When performing process control calculations, the use of a seven-day *moving average* is recommended. The moving average is a mathematical method to level the impact of any one test result.

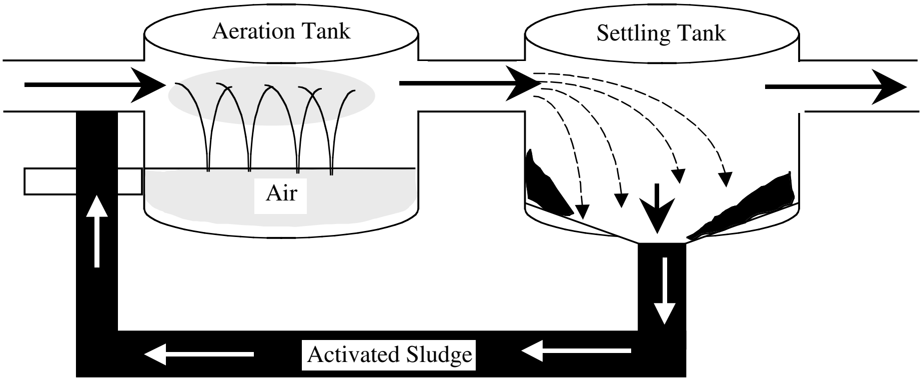


**FIGURE 26.1** The activated sludge process.

The moving average is determined by adding all of the test results collected during the past 7 day and dividing by the number of tests.

$$\text{Moving average} = \frac{\text{Test 1} + \text{Test 2} + \ldots + \text{Test 6} + \text{Test 7}}{\text{No. of tests performed over 7 days}} \tag{26.1}$$

### Example 26.1

*Problem*

Calculate the 7-day moving average for days 7, 8, and 9.

| Day | MLSS | Day | MLSS |
|---|---|---|---|
| 1 | 3340 | 6 | 2780 |
| 2 | 2480 | 7 | 2476 |
| 3 | 2398 | 8 | 2756 |
| 4 | 2480 | 9 | 2655 |
| 5 | 2558 | 10 | 2396 |

*Solution*

$$\text{Moving average, day 7} = \frac{3340 + 2480 + 2398 + 2480 + 2558 + 2780 + 2476}{7} = 2645$$

$$\text{Moving average, day 7} = \frac{2480 + 2398 + 2480 + 2558 + 2780 + 2476 + 2756}{7} = 2561$$

$$\text{Moving average, day 7} = \frac{2398 + 2480 + 2558 + 2780 + 2476 + 2756 + 2655}{7} = 2586$$

## BOD or COD Loading

When calculating BOD, COD, or SS loading on an aeration process (or any other treatment process), loading on the process is usually calculated as lb/day. The following equation is used:

$$\text{BOD, COD, or SS loading (lb/day)} = \text{mg/L} \times \text{MGD} \times 8.34\ \text{lb/gal} \tag{26.2}$$

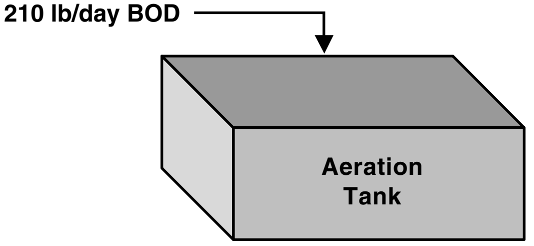


**FIGURE 26.2** Refers to Example 26.2.

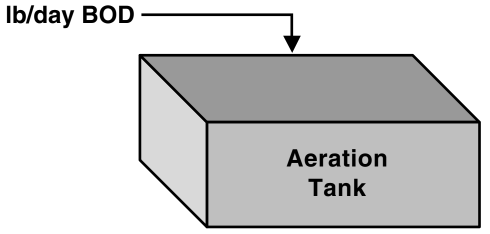


**FIGURE 26.3** Refers to Example 26.3.

### Example 26.2

*Problem*

The BOD concentration of the wastewater entering an aerator is 210 mg/L (see Figure 26.2). If the flow to the aerator is 1,550,000 gpd, what is the BOD loading in lb/day?

*Solution*

$$\text{BOD (lb/day)} = \text{BOD (mg/L)} \times \text{flow (MGD)} \times 8.34 \text{ lb/gal}$$

$$= 210 \text{ mg/L} \times 1.55 \text{ MGD} \times 8.34 \text{ lb/gal}$$

$$= 2715 \text{ lb/day}$$

### Example 26.3

*Problem*

The flow to an aeration tank is 2750 gpm. If the BOD concentration of the wastewater is 140 mg/L (see Figure 26.3), how many pounds of BOD are applied to the aeration tank daily?

*Solution*

First convert the gpm flow in gpm to gpd:

$$2750 \text{ gpm} \times 1440 \text{ min/day} = 3{,}960{,}000 \text{ gpd}$$

Then calculate lb/day BOD:

$$\text{BOD (lb/day)} = (\text{BOD (mg/L)} \times \text{flow (MGD)} \times 8.34 \text{ lb/gal}$$

$$= 140 \text{ mg/L} \times 3.96 \text{ MGD} \times 8.34 \text{ lb/day}$$

$$= 4624 \text{ lb/day}$$

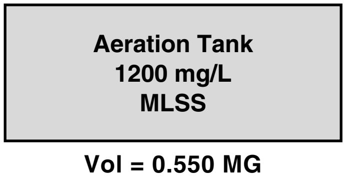


**FIGURE 26.4** Refers to Example 26.4.

### SOLIDS INVENTORY

In the activated biosolids process, it is important to control the amount of solids under aeration. The suspended solids in an aeration tank are called mixed liquor suspended solids (MLSS). To calculate the pounds of solids in the aeration tank, we need to know the MLSS concentration (in mg/L) and the aeration tank volume. Then pounds MLSS can be calculated as follows:

$$\text{MLSS (lb)} = \text{MLSS (mg/L)} \times \text{volume (MG)} \times 8.34\ \text{lb/gal} \tag{26.3}$$

#### Example 26.4

*Problem*

If the MLSS concentration is 1200 mg/L (see Figure 26.4), and the aeration tank has a volume of 550,000 gallons, how many pounds of suspended solids are in the aeration tank?

*Solution*

Referring to Equation 26.3:

$$\text{MLSS (lb)} = 1200\ \text{mg/L} \times 0.550\ \text{MG} \times 8.34\ \text{lb/gal}$$

$$= 5504\ \text{lb}$$

### FOOD-TO-MICROORGANISM RATIO (F/M RATIO)

The food-to-microorganism ratio (F/M ratio) is a process control method/calculation based upon maintaining a specified balance between available food materials (BOD or COD) in the aeration tank influent and the aeration tank mixed liquor volatile suspended solids (MLVSS) concentration (see Figure 26.5). The chemical oxygen demand test is sometimes used, because the results are available in a relatively short period of time. To calculate the F/M ratio, the following information is required:

- Aeration tank influent flow rate (MGD)
- Aeration tank influent BOD or COD (mg/L)
- Aeration tank MLVSS (mg/L)
- Aeration tank volume (MG)

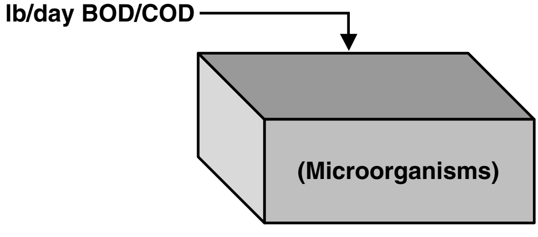


**FIGURE 26.5** F/M ratio process control unit.

Then,

$$\text{F/M ratio} = \frac{\text{primary effluent COD/BOD (mg/L)} \times \text{flow (MGD)} \times 8.34 \text{ lb/mg/L/MG}}{\text{MLVSS (mg/L)} \times \text{aerator volume (MG)} \times 8.34 \text{ lb/mg/L/MG}} \quad (26.4)$$

Typical F/M ratios for activated biosolids processes are shown in the following table:

| Process | BOD (lb)/MLVSS (lb) | COD (lb)/MLVSS (lb) |
|---|---|---|
| Conventional | 0.2–0.4 | 0.5–1.0 |
| Contact stabilization | 0.2–0.6 | 0.5–1.0 |
| Extended aeration | 0.05–0.15 | 0.2–0.5 |
| Pure oxygen | 0.25–1.0 | 0.5–2.0 |

### Example 26.5

*Problem*

The aeration tank influent BOD is 145 mg/L, and the aeration tank influent flow rate is 1.6 MGD. What is the F/M ratio if the MLVSS is 2300 mg/L and the aeration tank volume is 1.8 MG?

*Solution*

$$\text{F/M ratio} = \frac{145 \text{ mg/L} \times 1.6 \text{ MGD} \times 8.34 \text{ lb/mg/L/MG}}{2300 \text{ mg/L} \times 1.8 \text{ MG} \times 8.34 \text{ lb/mg/L/M}}$$

$$= 0.0.6 \text{ BOD (lb)/MLVSS (lb)}$$

**Key Point:** If the MLVSS concentration is not available, it can be calculated if the percent volatile matter (%VM) of the mixed liquor suspended solids (MLSS) is known.

$$\text{MLVSS} = \text{MLSS} \times \% \text{ (decimal) volatile matter (VM)} \quad (26.5)$$

**Key Point:** The food (F) value in the F/M ratio for computing loading to an activated biosolids process can be either BOD or COD. Remember, the reason for biosolids production in the activated biosolids process is to convert BOD to bacteria. One advantage of using COD over BOD for analysis of organic load is that COD is more accurate.

### Example 26.6

*Problem*

The aeration tank contains 2885 mg/L of MLSS. Lab tests indicate the MLSS is 66% volatile matter. What is the MLVSS concentration in the aeration tank?

*Solution*

$$\text{MLVSS (mg/L)} = 2885 \text{ mg/L} \times 0.66 = 1904 \text{ mg/L}$$

## Required MLVSS Quantity (pounds)

The pounds of MLVSS required in the aeration tank to achieve the optimum F/M ratio can be determined from the average influent food (BOD or COD) and the desired F/M ratio:

$$\text{MLVSS (lb)} = \frac{\text{primary effluent BOD or COD} \times \text{flow (MGD)} \times 8.34 \text{ lb/gal}}{\text{desired F/M ratio}} \tag{26.6}$$

The required pounds of MLVSS determined by this calculation can then be converted to a concentration value by:

$$\text{MLVSS (mg/L)} = \frac{\text{desired MLVSS (lb)}}{\text{aeration volume (MG)} \times 8.34 \text{ lb/gal}} \tag{26.7}$$

**Example 26.7**

*Problem*

The aeration tank influent flow is 4.0 MGD, and the influent COD is 145 mg/L. The aeration tank volume is 0.65 MG. The desired F/M ratio is 0.3 COD (lb)/MLVSS (lb). How many pounds of MLVSS must be maintained in the aeration tank to achieve the desired F/M ratio? What is the required concentration of MLVSS in the aeration tank?

*Solution*

$$\text{MLVSS} = \frac{145 \text{ mg/L} \times 4.0 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.3 \text{ COD (lb)/MLVSS (lb)}} = 16{,}124 \text{ lb MLVSS}$$

$$\text{MLVSS (mg/L)} = \frac{16{,}124 \text{ lb MLVSS}}{0.65 \text{ MG} \times 8.34 \text{ lb/gal}} = 2975 \text{ mg/L MLVSS}$$

### Calculating Waste Rates Using F/M Ratio

Maintaining the desired F/M ratio is accomplished by controlling the MLVSS level in the aeration tank. This may be accomplished by adjustment of return rates; however, the most practical method is by proper control of the waste rate:

$$\text{Waste volatile solids (lb/day)} = \text{Actual MLVSS (lb)} - \text{desired MLVSS (lb)} \tag{26.8}$$

If the desired MLVSS is greater than the actual MLVSS, wasting is stopped until the desired level is achieved. Practical considerations require that the required waste quantity be converted to a required volume of waste per day. This is accomplished by converting the waste pounds to flow rate in million gallons per day or gallons per minute:

$$\text{Waste (MGD)} = \frac{\text{waste volatile solids (lb/day)}}{\text{waste volatile concentration (mg/L)} \times 8.34 \text{ lb/gal}} \tag{26.9}$$

$$\text{Waste (gpm)} = \frac{\text{waste (MGD)} \times 1{,}000{,}000 \text{ gpd/MGD}}{1440 \text{ minute/day}} \tag{26.10}$$

**Key Point:** When F/M ratio is used for process control, the volatile content of the waste activated sludge should be determined.

**Example 26.8**

*Problem*

Given the following information, determine the required waste rate in gallons per minute to maintain an F/M ratio of 0.17 COD (lb)/MLVSS (lb).

Primary effluent COD = 140 mg/L
Primary effluent flow = 2.2 MGD
MLVSS (mg/L) = 3549 mg/L
Aeration tank volume = 0.75 MG
Waste volatile concentrations = 4440 mg/L (volatile solids)

$$\text{Actual MLVSS (lb)} = 3549 \text{ mg/L} \times 0.75 \text{ MG} \times 8.34 \text{ lb/gal} = 22{,}199 \text{ lb}$$

$$\text{Required MLVSS (lb)} = \frac{140 \text{ mg/L} \times 2.2 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.17 \text{ lb COD/lb MLVSS}} = 15{,}110 \text{ lb MLVSS}$$

$$\text{Waste (lb/day)} = 22{,}199 \text{ lb} - 15{,}110 \text{ lb} = 7089 \text{ lb}$$

$$\text{Waste (MGD)} = \frac{7089 \text{ lb/day}}{4440 \text{ mg/L} \times 8.34 \text{ lb/gal}} = 0.19 \text{ MGD}$$

$$\text{Waste (gpm)} = \frac{0.19 \text{ MGD} \times 1{,}000{,}000 \text{ gpd/MGD}}{1440 \text{ min/day}} = 132 \text{ gpm}$$

## Gould Biosolids Age

*Biosolids age* refers to the average number of days a particle of suspended solids remains under aeration. It is a calculation used to maintain the proper amount of activated biosolids in the aeration tank. This calculation is sometimes referred to as the *Gould biosolids age* so that it is not confused with similar calculations, such as solids retention time (or mean cell residence time). When considering sludge age, in effect we are calculating how many day of suspended solids are in the aeration tank. For example, if 3000 lb of SS enter an aeration tank daily and the aeration tank contains 12,000 lb of SS, then when 4 days of solids are in the aeration tank we have a sludge age of 4 days.

$$\text{Sludge age (day)} = \frac{\text{SS in tank (lb)}}{\text{SS added (lb/day)}} \tag{26.11}$$

### Example 26.9

*Problem*

A total of 2740 lb/day suspended solids enters an aeration tank in the primary effluent flow. If the aeration tank has a total of 13,800 lb of mixed liquor suspended solids, what is the biosolids age in the aeration tank?

*Solution*

Referring to Equation 26.11:

$$\text{Sludge age (day)} = \frac{13{,}800 \text{ lb}}{2740 \text{ lb/day}}$$

$$= 5.0 \text{ days}$$

## Mean Cell Residence Time (MCRT)

*Mean cell residence time* (MCRT), sometimes called *sludge retention time*, is another process control calculation used for activated biosolids systems. MCRT represents the average length of time an activated biosolids particle remains in the activated biosolids system. It can also be defined as the length of time required at the current removal rate to remove all the solids in the system.

$$\text{Mean cell residence time (day)} = \frac{\text{MLSS mg/L} \times (\text{aeration volume} + \text{clarifier volume}) \times 8.34\ \text{lb/mg/L/MG}}{[\text{WAS (mg/L)} \times \text{WAS flow} \times 8.34] + (\text{TSS out} \times \text{flow out} \times 8.34)} \quad (26.12)$$

✔ **Key Point:** MCRT can be calculated using only the aeration tank solids inventory. When comparing plant operational levels to reference materials, you must determine which calculation the reference manual uses to obtain its example values. Other methods are available to determine the clarifier solids concentrations; however, the simplest method assumes that the average suspended solids concentration is equal to the solids concentration of the aeration tank.

### Example 26.10

*Problem*

Given the following data, what is the MCRT?

Aeration volume =1,000,000 gal
Clarifier volume = 600,000 gal
Flow = 5.0 MGD
Waste rate = 0.085 MGD
MLSS (mg/L) = 2500 mg/L
Waste (mg/L) = 6400 mg/L
Effluent TSS = 14 mg/L

*Solution*

$$\text{MRCT} = \frac{2500\ \text{mg/L} \times (1.0\ \text{MG} + 0.60\ \text{MG}) \times 8.34}{(6400\ \text{mg/L} \times 0.085\ \text{MGD} \times 8.34) + (14\ \text{mg/L} \times 5.0\ \text{MGD} \times 8.34)}$$

$$= 6.5\ \text{days}$$

### Waste Quantities/Requirements

The MCRT for process control requires determination of the optimum range for MCRT values. This is accomplished by comparison of the effluent quality with MCRT values. When the optimum MCRT is established, the quantity of solids to be removed (wasted) is determined by:

$$\text{Waste (lb/day)} = \frac{\text{MLSS} \times [\text{aeration (MG)} + \text{clarifier (MG)}] \times 8.34\ \text{lb/gal}}{\text{desired MCRT}} - (\text{TSS}_{\text{out}} \times \text{flow} \times 8.34\ \text{lb/gal}) \quad (26.13)$$

### Example 26.11

$$\text{Waste quality (lb/day)} = \frac{3400\ \text{mg/L} \times (1.4\ \text{MG} + 0.50\ \text{MG}) \times 8.34\ \text{lb/gal}}{8.6\ \text{days}} - (10\ \text{mg/L} \times 5.0\ \text{MGD} \times 8.34\ \text{lb/gal})$$

$$= 5848\ \text{lb}$$

### Waste Rate in Million Gallons/Day

When the quantity of solids to be removed from the system is known, the desired waste rate in million gallons per day can be determined. The unit used to express the rate (MGD, gpd, gpm) is a function of the volume of waste to be removed and the design of the equipment.

$$\text{Waste (MGD)} = \frac{\text{waste pounds/day}}{\text{WAS concentration (mg/L)} \times 8.34 \text{ lb/gal}}$$

$$\text{Waste (gpm)} = \frac{\text{waste (MGD)} \times 1{,}000{,}000 \text{ gpd/MGD}}{1440 \text{ minutes/day}} \tag{26.15}$$

### Example 26.12

*Problem*

Given the following data, determine the required waste rate to maintain an MCRT of 8.8 days.

MLSS (mg/L) = 2500 mg/L
Aeration volume = 1.20 MG
Clarifier volume = 0.20 MG
Effluent TSS = 11 mg/L
Effluent flow = 5.0 MGD
Waste concentration = 6000 mg/L

*Solution*

$$\text{Waste (lb/day)} = \frac{2500 \text{ mg/L} \times (1.20 \text{ MG} + 0.20 \text{ MG}) \times 8.34}{8.8 \text{ days}} - (11 \text{ mg/L} \times 5.0 \text{ MGD} \times 8.34)$$

$$= 3317 \text{ lb/day} - 459 \text{ lb/day}$$

$$= 2858 \text{ lb/day}$$

$$\text{Waste (lb/day)} = \frac{2858 \text{ lb/day}}{6000 \text{ mg/L} \times 8.34} = 0.057 \text{ MGD}$$

$$\text{Waste (gpm)} = \frac{0.057 \text{ MGD} \times 1{,}000{,}000 \text{ gpd/MGD}}{1440 \text{ min/day}} = 40 \text{ gpm}$$

## Estimating Return Rates from $SSV_{60}$

Many methods are available for estimation of the proper return biosolids rate. A simple method described in the *Operation of Wastewater Treatment Plants: Field Study Programs* (1986), developed by the California State University, Sacramento, uses the 60-minute percent settled sludge volume (%$SSV_{60}$). The %$SSV_{60}$ test results can provide an approximation of the appropriate return activated biosolids rate. This calculation assumes that the $SSV_{60}$ results are representative of the actual settling occurring in the clarifier. If this is true, the return rate in percent should be approximately equal to the $SSV_{60}$. To determine the approximate return rate in million gallons per day (MGD), the influent flow rate, the current return rate, and the $SSV_{60}$ must be known. The results of this calculation can then be adjusted based upon sampling and visual observations to develop the optimum return biosolids rate.

✓ **Key Point:** The $\%SSV_{60}$ must be converted to a decimal percent and total flow rate (wastewater flow and current return rate in million gallons per day) must be used.

$$\text{Estimated return rate (MGD)} = \left[\text{Influent flow (MGD)} + \text{current return flow (MGD)}\right] \times \%SSV_{60} \tag{26.16}$$

$$\text{RAS rate (gpm)} = \frac{\text{return biosolids rate (gpd)}}{1440 \text{ min/day}} \tag{26.17}$$

These equations assume that:

- $\%SSV_{60}$ is representative.
- Return rate in percent equals $\%SSV_{60}$.
- Actual return rate is normally set slightly higher to ensure organisms are returned to the aeration tank as quickly as possible. The rate of return must be adequately controlled to prevent the following:
  - Aeration and settling hydraulic overloads
  - Low MLSS levels in the aerator
  - Organic overloading of aeration
  - Septic return-activated biosolids
  - Solids loss due to excessive biosolids blanket depth

### Example 26.13

*Problem*

The influent flow rate is 5.0 MGD, and the current return-activated sludge flow rate is 1.8 MGD. The $\%SSV_{60}$ is 37%. Based upon this information, what should be the return biosolids rate in million gallons per day (MGD)?

*Solution*

$$\text{Return (MGD)} = (5.0 \text{ MGD} + 1.8 \text{ MGD}) \times 0.37 = 2.5 \text{ MGD}$$

## Sludge Volume Index (SVI)

The *sludge volume index* (SVI) is a measure (an indicator) of the settling quality (a quality indicator) of the activated biosolids. As the SVI increases, the biosolids settle more slowly, do not compact as well, and are likely to result in an increase in effluent suspended solids. As the SVI decreases, the biosolids become denser, settling is more rapid, and the biosolids age. SVI is the volume in milliliters occupied by 1 gram of activated biosolids. For the settled biosolids volume (mL/L) and the mixed liquor suspended solids (MLSS) calculation, milligrams per liter are required. The proper SVI range for any plant must be determined by comparing SVI values with plant effluent quality.

$$\text{Sludge volume index (SVI)} = \frac{\text{SSV (mL/L)} \times 1000}{\text{MLSS (mg/L)}} \tag{26.18}$$

### Example 26.14

*Problem*

The $SSV_{30}$ is 365 mL/L, and the MLSS is 2365 mg/L. What is the SVI?

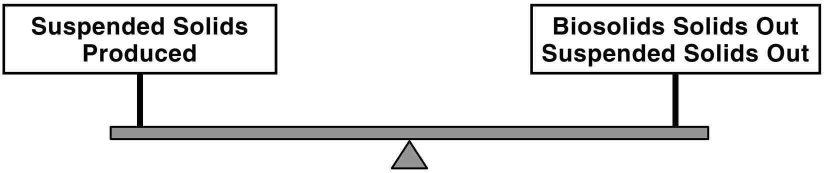


**FIGURE 26.6** Biological process mass balance.

*Solution*

$$\text{Sludge volume index (SVI)} = \frac{365 \text{ mL/L} \times 1000}{2365 \text{ mg/L}} = 154.3$$

The SVI is 154.3. What does this mean? It means is that the system is operating normally with good settling and low effluent turbidity. How do we know this? We know this because we can compare the 154.3 result with the parameters listed below to obtain the expected condition (the result).

| Sludge Volume Index (SVI) | Expected Conditions (Indications) |
|---|---|
| Less than 100 | Old biosolids — possible pin floc<br>Effluent turbidity increasing |
| 100–250 | Normal operation — good settling<br>Low effluent turbidity |
| Greater than 250 | Bulking biosolids — poor settling<br>High effluent turbidity |

## Mass Balance: Settling Tank Suspended Solids

Solids are produced whenever biological processes are used to remove organic matter from wastewater (see Figure 26.6). Mass balance for anaerobic biological processes must take into account both the solids removed by physical settling processes and the solids produced by biological conversion of soluble organic matter to insoluble suspended matter organisms. Research has shown that the amount of solids produced per pound of BOD removed can be predicted based upon the type of process being used. Although the exact amount of solids produced can vary from plant to plant, research has developed a series of *K* factors that can be used to estimate the solids production for plants using a particular treatment process. These average factors provide a simple method to evaluate the effectiveness of a facility's process control program. The mass balance also provides an excellent mechanism for evaluating the validity of process control and effluent monitoring data generated. Recall that Table 13.1 lists average *K* factors in pounds of solids produced per pound of BOD removed for selected processes.

### Mass Balance Calculation

$$\text{BOD in (lb)} = \text{BOD (mg/L)} \times \text{flow (MGD)} \times 8.34 \text{ lb/gal}$$

$$\text{BOD out (lb)} = \text{BOD (mg/L)} \times \text{flow (MGD)} \times 8.34 \text{ lb/gal}$$

$$\text{Solids produced (lb/day)} = [\text{BOD in (lb)} - \text{BOD out (lb)}] \times K$$

$$\text{TSS out (lb/day)} = \text{TSS out (mg/L)} \times \text{flow (MGD)} \times 8.34 \text{ lb/gal} \tag{26.19}$$

$$\text{Waste (lb/day)} = \text{waste (mg/L)} \times \text{flow (MGD)} \times 8.34 \text{ lb/gal}$$

$$\text{Solids removed (lb/day)} = \text{TSS out (lb/day)} + \text{waste (lb/day)}$$

$$\text{\% Mass balance} = \frac{(\text{solids produced} - \text{solids removed}) \times 100}{\text{solids produced}}$$

### Biosolids Waste Based Upon Mass Balance

$$\text{Waste rate (MGD)} = \frac{\text{solids produced (lb/day)}}{\text{waste concentration} \times 8.34 \text{ lb/gal}} \tag{26.20}$$

**Example 26.15**

*Problem*

Given the following data, determine the mass balance of the biological process and the appropriate waste rate to maintain current operating conditions:

| Process | Extended Aeration (No Primary) | |
|---|---|---|
| Influent | Flow | 1.1 MGD |
| | BOD | 220 mg/L |
| | TSS | 240 mg/L |
| Effluent | Flow | 1.5 MGD |
| | BOD | 18 mg/L |
| | TSS | 22 mg/L |
| Waste | Flow | 24,000 gpd |
| | TSS | 8710 mg/L |

*Solution*

$$\text{BOD in} = 220 \text{ mg/L} \times 1.1 \text{ MGD} \times 8.34 \text{ lb/gal} = 2018 \text{ lb/day}$$

$$\text{BOD out} = 18 \text{ mg/L} \times 1.1 \text{ MGD} \times 8.34 \text{ lb/gal} = 165 \text{ lb/day}$$

$$\text{BOD removed} = 2018 \text{ lb/day} - 165 \text{ lb/day} = 1853 \text{ lb/day}$$

$$\text{Solids produced} = 1853 \text{ lb/day} \times 0.65 \text{ lb/lb BOD} = 1204 \text{ lb solids/day}$$

$$\text{Solids out (lb/day)} = 22 \text{ mg/L} \times 1.1 \text{ MGD} \times 8.34 \text{ lb/gal} = 202 \text{ lb/day}$$

$$\text{Sludge out (lb/day)} = 8710 \text{ mg/L} \times 0.024 \text{ MGD} \times 8.34 \text{ lb/gal} = 1743 \text{ lb/day}$$

$$\text{Solids removed (lb/day)} = (202 \text{ lb/day} + 1743 \text{ lb/day}) = 1945 \text{ lb/day}$$

$$\text{Mass balance (\%)} = \frac{(1204 \text{ lb solids/day} - 1945 \text{ lb/day}) \times 100}{1204 \text{ lb/day}} = 62\%$$

The mass balance indicates that:

- The sampling points, collection methods, and/or laboratory testing procedures are producing nonrepresentative results.
- The process is removing significantly more solids than is required; additional testing should be performed to isolate the specific cause of the imbalance.

To assist in the evaluation, the waste rate based upon the mass balance information can be calculated.

$$\text{Waste (GPD)} = \frac{\text{solids produced (lb/day)}}{\text{waste TSS (mg/L)} \times 8.34} \tag{26.21}$$

$$\text{Waste (GPD)} = \frac{1204\ \text{lb/day} \times 1{,}000{,}000}{8710\ \text{mg/L} \times 8.34} = 16{,}575\ \text{gpd}$$

## Oxidation Ditch Detention Time

*Oxidation ditch systems* may be used where the treatment of wastewater is amendable to aerobic biological treatment and the plant design capacities generally do not exceed 1.0 MGD. The oxidation ditch is a form of aeration basin where the wastewater is mixed with return biosolids (see Figure 26.7). The oxidation ditch is essentially a modification of a completely mixed activated biosolids system used to treat wastewater from small communities. This system can be classified as an extended aeration process and is considered to be a low loading rate system. This type of treatment facility can remove 90% or more of influent BOD. Oxygen requirements will generally depend on the maximum diurnal organic loading, degree of treatment, and suspended solids concentration to be maintained in the aerated channel mixed liquor suspended solids. Detention time is the length of time required for a given flow rate to pass through a tank. Detention time is not normally calculated for aeration basins, but it is calculated for oxidation ditches.

✔ **Key Point:** When calculating detention time it is essential that the time and volume units used in the equation are consistent with each other.

$$\text{Detention time (hr)} = \frac{\text{volume of oxidation ditch (gal)}}{\text{flow rate (gph)}} \tag{26.22}$$

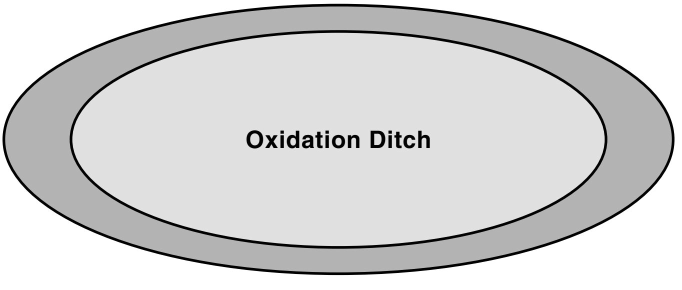


**FIGURE 26.7** Oxidation ditch.

**Example 26.16**

*Problem*

An oxidation ditch has a volume of 160,000 gallons. If the flow to the oxidation ditch is 185,000 gpd, what is the detention time in hours?

*Solution*

Because detention time is desired in hours, the flow must be expressed as gph:

$$\frac{185,000 \text{ gpd}}{24 \text{ hr/day}} = 7708 \text{ gph}$$

Now calculate detention time.

Referring to Equation 26.22:

$$\text{Detention time (hr)} = \frac{160,000 \text{ gallons}}{7708 \text{ gph}}$$

$$= 20.8 \text{ hr}$$

# 27 Treatment Ponds

**TOPICS**



The primary goals of wastewater treatment ponds focus on simplicity and flexibility of operation, protection of the water environment, and protection of public health. Moreover, ponds are relatively easy to build and manage, they accommodate large fluctuations in flow, and they can also provide treatment that approaches the effectiveness of conventional systems (producing a highly purified effluent) at much lower cost. It is the cost (the economics) that drives many managers to decide on the pond option of treatment. The actual degree of treatment provided in a pond depends on the type and number of ponds used. Ponds can be used as the sole type of treatment, or they can be used in conjunction with other forms of wastewater treatment; that is, other treatment processes are followed by a pond or a pond is followed by other treatment processes. Ponds can be classified based upon their location in the system, by the type of wastes they receive, and by the main biological process occurring in the pond.

## TREATMENT POND PARAMETERS

Before we discuss process control calculations, it is important first to describe the calculations for determining the area, volume, and flow rate parameters that are crucial to making treatment pond calculations.

### Determining Pond Area (Inches)

$$\text{Area (acres)} = \frac{\text{area} \left(\text{ft}^2\right)}{43{,}560 \text{ ft}^2/\text{acre}} \tag{27.1}$$

### Determining Pond Volume (Acre-Feet)

$$\text{Volume (acre-feet)} = \frac{\text{volume} \left(\text{ft}^3\right)}{43{,}560 \text{ ft}^2/\text{acre-foot}} \tag{27.2}$$

### Determining Flow Rate (Acre-Feet/Day)

$$\text{Flow (acre-feet/day)} = \text{Flow (MGD)} \times 3069 \text{ acre-feet/MG} \tag{27.3}$$

✓ **Key Point:** Acre-feet (ac-ft) is a unit that can cause confusion, especially for those not familiar with pond or lagoon operations. One acre-foot is the volume of a box with a 1-acre top and 1 ft of depth, but the top does not have to be an even number of acres in size to use acre-feet.

### Determining Flow Rate (Acre-Inches/Day)

$$\text{Flow (acre-inches/day)} = \text{flow (MGD)} \times 36.8 \text{ acre-inches/MG} \tag{27.4}$$

## TREATMENT POND PROCESS CONTROL CALCULATIONS

Despite a lack of recommended process control calculations for the treatment pond, several calculations may be helpful in evaluating process performance or identifying causes of poor performance. These include hydraulic detention time, BOD loading, organic loading rate, BOD removal efficiency, population loading, and hydraulic loading rate. In the following we provide a few calculations that might be helpful in pond performance evaluation and identification of causes of poor performance process along with other calculations and/or equations that may be helpful.

### Hydraulic Detention Time (Days)

$$\text{Hydraulic detention time (day)} = \frac{\text{pond volume (acre-feet)}}{\text{influent flow (acre-feet/day)}} \tag{27.5}$$

✓ **Key Point:** Normally, hydraulic detention time ranges from 30 to 120 days for stabilization ponds.

#### Example 27.1

*Problem*

A stabilization pond has a volume of 54.5 acre-feet. What is the detention time in days when the flow is 0.35 MGD?

*Solution*

$$\text{Flow (ac-ft/day)} = 0.35 \text{ MGD} \times 3.069 \text{ ac-ft/MG}$$

$$= 1.07 \text{ ac-ft/day}$$

$$\text{DT days} = \frac{54.5 \text{ acre/ft}}{1.07 \text{ ac-ft/day}}$$

$$= 50.9 \text{ days}$$

### BOD Loading

When calculating BOD loading on a wastewater treatment pond, the following equation is used:

$$\text{BOD loading (lb/day)} = \text{BOD (mg/L)} \times \text{flow (MGD)} \times 8.34 \text{ lb/gal} \tag{27.6}$$

### Example 27.2

*Problem*

Calculate the BOD loading (lb/day) on a pond if the influent flow is 0.3 MBD with a BOD of 200 mg/L.

*Solution*

Referring to Equation 27.6:

$$\text{BOD loading (lb/day)} = 200 \text{ mg/L} \times 0.3 \text{ MGD} \times 8.34 \text{ lb/gal}$$

$$= 500 \text{ lb/day}$$

## Organic Loading Rate

Organic loading can be expressed as pounds of BOD per acre per day (most common), pounds of BOD per-acre foot per day, or people per acre per day:

$$\text{Organic loading } (\text{lb BOD/acre/day}) = \frac{\text{BOD } (\text{mg/L}) \times \text{influent flow (MGD)} \times 8.34}{\text{pond area (acres)}} \quad (27.7)$$

✔ **Key Point:** Normal range is 10 to 50 lb BOD per day per acre.

### Example 27.3

*Problem*

A wastewater treatment pond has an average width of 370 ft and an average length of 730 ft. The influent flow rate to the pond is 0.10 MGD with a BOD concentration of 165 mg/L. What is the organic loading rate (to the pound) in pounds per day per acre (lb/d/ac)?

*Solution*

$$730 \text{ ft} \times 370 \text{ ft} \times \frac{1 \text{ ac}}{43,560 \text{ ft}^2} = 6.2 \text{ acre}$$

$$0.10 \text{ MGD} \times 165 \text{ mg/L} \times 8.34 \text{ lb/gal} = 138 \text{ lb/day}$$

$$\frac{138 \text{ lb/d}}{6.2 \text{ ac}} = 22.2 \text{ lb/d/acre}$$

## BOD Removal Efficiency

As mentioned, the efficiency of any treatment process is its effectiveness in removing various constituents from the water or wastewater. BOD removal efficiency is therefore a measure of the effectiveness of the wastewater treatment pond in removing BOD from the wastewater:

$$\%\text{ BOD removed} = \frac{\text{BOD removed } (\text{mg/L})}{\text{BOD total } (\text{mg/L})} \times 100$$

### Example 27.4

*Problem*

The BOD entering a waste treatment pond is194 mg/L. If the BOD in the pond effluent is 45 mg/L, what is the BOD removal efficiency of the pond?

$$\% \text{ BOD removed} = \frac{\text{BOD removal (mg/L)}}{\text{BOD total (mg/L)}} \times 100$$

$$= \frac{149 \text{ mg/L}}{194 \text{ mg/L}} \times 100$$

$$= 77\%$$

## Population Loading

$$\text{Population loading (people/acre/day)} = \frac{\text{BOD (mg/L)} \times \text{influent flow (MGD)} \times 8.34}{\text{pond area (acres)}} \tag{27.8}$$

## Hydraulic Loading (Inches/Day) (Overflow Rate)

$$\text{Hydraulic loading (inches/day)} = \frac{\text{influent flow (acre-inches/day)}}{\text{pond area (acres)}} \tag{27.9}$$

# 28 Chemical Dosage Calculations

## TOPICS



(*Note:* Earlier we discussed calculations used in the chlorination process; thus, a certain amount of information presented in this chapter is related to similar information previously presented. In this chapter, we again discuss chlorination, but as it relates to wastewater treatment.)

## CHEMICAL DOSING

Chemicals are used extensively in wastewater treatment (and water treatment) operations. Plant operators add chemicals to various unit processes for slime-growth control, corrosion control, odor control, grease removal, biological oxygen demand (BOD) reduction, pH control, biosolids-bulking control, ammonia oxidation, and bacterial reduction, among other uses. In order to apply any chemical dose correctly, it is important to make certain dosage calculations. One of the most frequently used calculations in wastewater/water mathematics is the dosage or loading. The general types of mg/L to lb/d or lb calculations are used for chemical dosage, BOD, chemical oxygen demand (COD), SS loading/removal, pounds of solids under aeration, and WAS pumping rate. These calculations are usually made using either Equation 28.1 or Equation 28.2.

$$\text{Chemical (mg/L)} \times \text{MGD flow} \times 8.34 \text{ lb/gal} = \text{lb/day} \tag{28.1}$$

$$\text{Chemical (mg/L)} \times \text{MG volume} \times 8.34 \text{ lb/gal} = \text{lb} \tag{28.2}$$

**Key Point:** If the mg/L concentration represents concentration in a flow, then million gallons per day (MGD) flow is used as the second factor; however, if the concentration pertains to a tank or pipeline volume, then million gallons (MG) volume is used as the second factor.

**Key Point:** Typically, especially in the past, parts per million (ppm) was used as an expression of concentration, because 1 mg/L = 1 ppm; however, current practice is to use mg/L as the preferred expression of concentration.

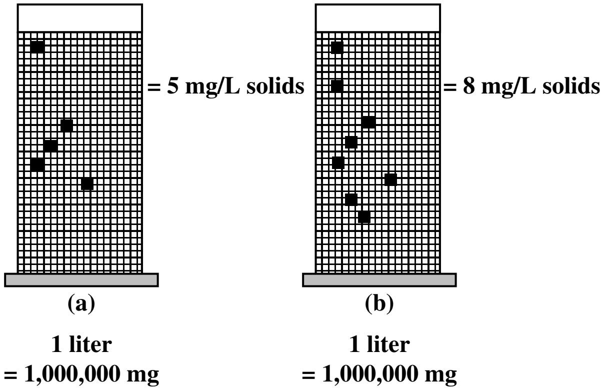


**FIGURE 28.1** (a) and (b) 1 liter solutions.

## CHEMICAL FEED RATE

In chemical dosing, a measured amount of chemical is added to the wastewater (or water). The amount of chemical required depends on the type of chemical used, the reason for dosing, and the flow rate being treated. The two expressions most often used to describe the amount of chemical added or required are:

- Milligrams per liter (mg/L)
- Pounds per day (lb/day)

A milligram per liter is a measure of concentration. For example, consider Figure 28.1a and Figure 28.1b. In this figure, it is apparent that the mg/L concentration expresses a ratio of the milligrams chemical in each liter of water. As shown below, if a concentration of 5 mg/L is desired, then a total of 15 mg chemical would be required to treat 3 liters:

$$\frac{5\text{ mg} \times 3}{\text{L} \times 3} = \frac{15\text{ mg}}{3\text{ L}}$$

The amount of chemical required, therefore, depends on two factors:

- Desired concentration (mg/L)
- Amount of wastewater to be treated (normally expressed as MGD)

To convert from mg/L to lb/day, use Equation 28.1.

### Example 28.1

*Problem*

Determine the chlorinator setting (lb/day) required to treat a flow of 5 MGD with a chemical dose of 3 mg/L.

*Solution*

$$\text{Chemical (lb/day)} = \text{chemical (mg/L)} \times \text{flow (MGD)} \times 8.34\text{ lb/gal}$$

$$= 3\text{mg/L} \times 5\text{ MGD} \times 8.34\text{ lb/gal}$$

$$= 125\text{ lb/day}$$

### Example 28.2

*Problem*

The desired dosage for a dry polymer is 10 mg/L. If the flow to be treated is 2,100,000 gpd, how many lb/day of polymer will be required?

*Solution*

$$\text{Polymer (lb/day)} = \text{polymer (mg/L)} \times \text{flow (MGD)} \times 8.34 \text{ lb/day}$$

$$= 10 \text{ mg/L polymer} \times 2.10 \text{ MGD} \times 8.34 \text{ lb/day}$$

$$= 175 \text{ lb/day}$$

✓ **Key Point:** To calculate chemical dose for tanks or pipelines, a modified equation must be used. Instead of MGD flow, MG volume is used:

$$\text{Chemical (lb)} = \text{chemical (mg/L)} \times \text{tank volume (MG)} \times 8.34 \text{ lb/gal} \tag{28.3}$$

### Example 28.3

*Problem*

To neutralize a sour digester, one pound of lime is added for every pound of volatile acids in the digester biosolids. If the digester contains 300,000 gal of biosolids with a volatile acid (VA) level of 2200 mg/L, how many pounds of lime should be added?

*Solution*

Because volatile acid concentration is 2200 mg/L, the lime concentration should also be 2200 mg/L:

$$\text{Lime required (lb)} = \text{Lime (mg/L)} \times \text{digester volume (MG)} \times 8.34 \text{ lb/gal}$$

$$= 2200 \text{ mg/L} \times 0.30 \text{ MG} \times 8.34 \text{ lb/gal}$$

$$= 5504 \text{ lb}$$

## Chlorine Dose, Demand, and Residual

Chlorine is a powerful oxidizer that is commonly used in wastewater and water treatment for disinfection and in wastewater treatment for odor control, bulking control, and other applications. When chlorine is added to a unit process, we want to ensure that a measured amount is added. Chlorine dose depends on two considerations — the chlorine demand and the desired chlorine residual:

$$\text{Chlorine dose} = \text{chlorine demand} + \text{chlorine residual} \tag{28.4}$$

### Chlorine Dose

To describe the amount of chemical added or required, we use Equation 28.1:

$$\text{Chemical (mg/L)} \times \text{MGD flow} \times 8.34 \text{ lb/gal} = \text{lb/day}$$

### Example 28.4

*Problem*

Determine the chlorinator setting (lb/day) needed to treat a flow of 8 MGD with a chlorine dose of 6 mg/L.

*Solution*

$$\text{mg/L} \times \text{MGD} \times 8.34 = \text{lb/day}$$

$$6 \text{ mg/L} \times 8 \text{ MGD} \times 8.34 \text{ lb/gal} = 400 \text{ lb/day}$$

### Chlorine Demand

The *chlorine demand* is the amount of chlorine used to react with various components of the water such as harmful organisms and other organic and inorganic substances. When the chlorine demand has been satisfied, these reactions cease.

### Example 28.5

*Problem*

The chlorine dosage for a secondary effluent is 6 mg/L. If the chlorine residual after a 30-minute contact time is found to be 0.5 mg/L, what is the chlorine demand (expressed in mg/L)?

*Solution*

Referring to Equation 28.4:

$$6 \text{ mg/L} = x \text{ mg/L} + 0.5 \text{ mg/L}$$

$$6 \text{ mg/L} - 0.5 \text{ mg/L} = x \text{ mg/L}$$

$$x = 5.5 \text{ mg/L chlorine demand}$$

### Chlorine Residual

Chlorine residual is the amount of chlorine remaining after the demand has been satisfied.

### Example 28.6

*Problem*

What should the chlorinator setting be (l/bday) to treat a flow of 3.9 MGD if the chlorine demand is 8 mg/L and a chlorine residual of 2 mg/L is desired?

*Solution*

First calculate the chlorine dosage in mg/L using Equation 28.4:

$$\text{Chlorine dose (mg/L)} = 8 \text{ mg/L} + 2 \text{ mg/L}$$

$$= 10 \text{ mg/L}$$

Then calculate the chlorine dosage (feed rate) in lb/day using Equation 28.1:

$$10 \text{ mg/L} \times 3.9 \text{ MGD} \times 8.34 \text{ lb/gal} = 325 \text{ lb/day chlorine}$$

## Hypochlorite Dosage

Hypochlorite is less hazardous than chlorine; therefore, it is often used as a substitute chemical for elemental chlorine. Hypochlorite is similar to strong bleach and comes in two forms: dry calcium hypochlorite (often referred to as HTH) and liquid sodium hypochlorite. Calcium hypochlorite contains about 65% available chlorine; sodium hypochlorite contains about 12 to 15% available chlorine (in industrial strengths).

✔ **Key Point:** Because either type of hypochlorite is not 100% pure chlorine, more pounds per day must be fed into the system to obtain the same amount of chlorine for disinfection. This is an important economical consideration for those facilities thinking about substituting hypochlorite for chlorine. Some studies indicate that such a substitution can increase overall operating costs by up to three times compared to the cost of using chlorine.

To calculate the lb/day hypochlorite required, a two-step calculation is required:

$$\text{mg/L} \times \text{MGD} \times 8.34 = \text{lb/day}$$

$$\frac{\text{Chlorine (lb/d)}}{\frac{\%\ \text{available}}{100}} = \text{hypochlorite (lb/d)} \tag{28.5}$$

### Example 28.7

*Problem*

A total chlorine dosage of 10 mg/L is required to treat a particular wastewater. If the flow is 1.4 MGD and the hypochlorite has 65% available chlorine, how many lb/day of hypochlorite will be required?

*Solution*

First calculate the lb/d chlorine required using the mg/L to lb/day equation:

$$10\ \text{mg/L} \times 1.4\ \text{MGD} \times 8.34\ \text{lb/gal} = 117\ \text{lb/day}$$

Then calculate the lb/day hypochlorite required. Because only 65% of the hypochlorite is chlorine, more than 117 lb/day will be required:

$$\frac{117\ \text{lb/day chlorine}}{\frac{65\ \text{available chlorine}}{100}} = 180\ \text{lb/day hypochlorite}$$

### Example 28.8

*Problem*

A wastewater flow of 840,000 gpd requires a chlorine dose of 20 mg/L. If sodium hypochlorite (15% available chlorine) is to be used, how many lb/day of sodium hypochlorite are required? How many gal/day of sodium hypochlorite is this?

*Solution*

First calculate the lb/day chlorine required:

$$20\ \text{mg/L} \times 0.84\ \text{MGD} \times 8.34\ \text{lb/gal} = 140\ \text{lb/day chlorine}$$

Then calculate the lb/day sodium hypochlorite:

$$\frac{140\ \text{lb/day chlorine}}{\frac{15\ \text{available chlorine}}{100}} = 933\ \text{lb/day hypochlorite}$$

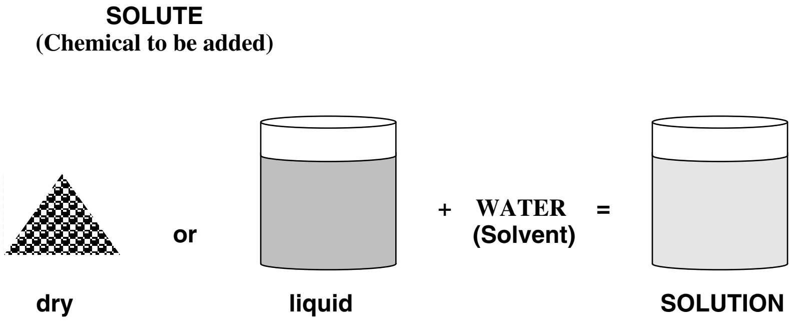


**FIGURE 28.2** Components of a solution.

Finally, calculate the gal/day sodium hypochlorite:

$$\frac{933 \text{ lb/day}}{8.34 \text{ lb/gal}} = 112 \text{ gal/day sodium hypochlorite}$$

### Example 28.9

*Problem*

How many pounds of chlorine gas are necessary to treat 5,000,000 gallons of wastewater at a dosage of 2 mg/L?

*Solution*

First calculate the pounds of chlorine required.

$$\text{Volume } (10^6 \text{ gal}) = \text{chlorine concentration (mg/L)} \times 8.34 = \text{lb chlorine}$$

Then,

$$(5 \times 10^6) \text{ gal} \times 2 \text{ mg/L} \times 8.34 = 83 \text{ lb chlorine}$$

## Chemical Solutions

A *water solution* is a homogeneous liquid consisting of the *solvent* (the substance that dissolves another substance) and the *solute* (the substance that dissolves in the solvent). Water is the solvent (see Figure 28.2). The solute (whatever it may be) may dissolve up to a certain point. This is called its *solubility* — that is, the solubility of the solute in the particular solvent (water) at a particular temperature and pressure. Remember, in chemical solutions, the substance being dissolved is the *solute*, and the liquid present in the greatest amount in a solution (and that does the dissolving) is the *solvent*. We should also be familiar with another term — *concentration*, which is the amount of solute dissolved in a given amount of solvent. Concentration is measured as:

$$\% \text{ Strength} = \frac{\text{wt. of solute}}{\text{wt. of solution}} \times 100 = \frac{\text{wt. of solute}}{\text{wt. of solute} + \text{solvent}} \times 100 \tag{28.6}$$

### Example 28.10

*Problem*

If 30 lb of chemical are added to 400 lb of water, what is the percent strength (by weight) of the solution?

*Solution*

$$\% \text{ Strength} = \frac{30 \text{ lb solute}}{400 \text{ lb water}} \times 100 = \frac{30 \text{ lb solute}}{30 \text{ lb solute} + 400 \text{ lb water}} \times 100$$

$$= \frac{30 \text{ lb solute}}{430 \text{ lb solute/water}} \times 100$$

$$= 7.0\%$$

It is important when making accurate computations of chemical strength to have a complete understanding of the dimensional units involved — for example, understanding exactly what milligrams per liter (mg/L) signifies:

$$\text{Milligrams per liter } (\text{mg/L}) = \frac{\text{milligrams of solute}}{\text{liters of solution}} \tag{28.7}$$

Another dimensional unit commonly used when dealing with chemical solutions is parts per million (ppm):

$$\text{Parts per million } (\text{ppm}) = \frac{\text{parts of solute}}{\text{million parts of solute}} \tag{28.8}$$

✓ **Key Point:** The “parts” component is usually a weight measurement; for example,

$$8 \text{ ppm} = \frac{8 \text{ lb solids}}{1{,}000{,}000 \text{ lb solution}}$$

$$8 \text{ ppm} = \frac{8 \text{ mg solids}}{1{,}000{,}000 \text{ mg solution}}$$

## Mixing Solutions of Different Strength

When different percent strength solutions are mixed, we use the following equations, depending upon the complexity of the problem:

$$\% \text{ Strength of mixture} = \frac{\text{chemical in mixture (lb)}}{\text{solution mixture (lb)}} \times 100 \tag{28.9}$$

$$\% \text{ Strength of mixture} = \frac{\text{lb chemical (sol. 1)} + \text{lb chemical (sol. 2)}}{\text{lb solution 1} + \text{lb solution 2}} \tag{28.10}$$

$$\% \text{ Strength of mixture} =$$

$$\frac{\dfrac{\text{sol. 1 (lb)} \times \% \text{ strength sol. 1}}{100} + \dfrac{\text{sol. 2 (lb)} \times \% \text{ strength sol. 2}}{100}}{\text{lb solution 1} + \text{lb solution 2}} \tag{28.11}$$

**Example 28.11**

*Problem*

If 25 lb of a 10% strength solution are mixed with 40 lb of 1% strength solutions, what is the percent strength of the solution mixture? First, refer to Equation 28.11:

$$\begin{aligned}\%\text{ Strength of mixture} &= \frac{(25\text{ lb}\times 0.1)+(40\text{ lb}\times 0.01)}{25\text{ lb}+40\text{ lb}}\\ &= \frac{2.5\text{ lb}+0.4\text{ lb}}{65\text{ lb}}\times 100\\ &= 4.5\%\end{aligned}$$

✔ **Key Point:** Percent strength should be expressed in terms of pounds of chemical per pounds of solution. That is, when solutions are expressed, for example, in terms of gallons, the gallons should be expressed as pounds before continuing with the percent strength calculations.

### Solution Mixtures Target Percent Strength

When two different percent strength solutions are mixed in order to obtain a desired quantity of solution and a target percent strength, we use Equation 28.11. After filling in the given information, we can find the unknown, *x*.

**Example 28.12**

*Problem*

What weights of a 3% solution and a 6% solution must be mixed to make 800 lb of a 4% solution?

*Solution*

Referring to Equation 28.11:

$$\begin{aligned}4 &= \frac{(x\text{ lb}\times 0.03)+[(800-x\text{ lb})\times 0.06]}{800\text{ lb}}\times 100\\ &= \frac{4\times 800}{100} = 0.03x+48-0.06x\\ 32 &= -0.03x+48\\ 0.03x &= 14\\ x &= 467\text{ lb of }3\%\text{ solution}\end{aligned}$$

Then, 800 – 467 = 333 lb of 6% solution.

### Solution Chemical Feeder Setting (gpd)

Calculating the gallons per day (gpd) feeder setting depends on how the solution concentration is expressed: lb/gal or percent. If the solution strength is expressed as lb/gal, use the following equation:

$$\text{Solution (gpd)} = \frac{\text{chemical (mg/L)}\times\text{flow (MGD)}\times 8.34\text{ lb/gal}}{\text{chemical solution (lb)}} \tag{28.12}$$

In water/wastewater operations, a standard trial-and-error method known as *jar testing* is conducted to determine optimum chemical dosage. Jar testing has been the accepted bench-testing procedure for many years. After jar testing results are analyzed to determine the best chemical dosage, actual calculations are made, as demonstrated by the following example problems.

### Example 28.13

*Problem*

Jar tests indicate that the best liquid alum dose for a water is 8 mg/L. The flow to be treated is 1.85 MGD. Determine the gallons per day setting for the liquid alum chemical feeder if the liquid alum contains 5.30 lb of alum per gallon of solution.

*Solution*

First, calculate the lb/day of dry alum required, using the mg/L to lb/day equation:

$$\begin{aligned}\text{lb/d} &= \text{dose}\ (\text{mg/L}) \times \text{flow}\ (\text{MGD}) \times 8.34\ \text{lb/gal} \\ &= 8\ \text{mg/L} \times 1.85\ \text{MGD} \times 8.34\ \text{lb/gal} \\ &= 123\ \text{lb/day dry alum}\end{aligned}$$

Then, calculate the gpd solution required:

$$\text{Alum solution (gpd)} = \frac{123\ \text{lb /day alum}}{5.30\ \text{lb alum/gal solution}}$$

$$\text{Feeder setting} = 23\ \text{gpd alum solution}$$

If the solution strength is expressed as a percent, we use the following equation:

$$\begin{aligned}&\text{Chemical}\ (\text{mg/L}) \times \text{flow treated}\ (\text{MGD}) \times 8.34\ \text{lb/gal} = \\ &\text{solution}\ (\text{mg/L}) \times \text{solution flow}\ (\text{MGD}) \times 8.34\ \text{lb/gal}\end{aligned} \tag{28.13}$$

### Example 28.14

*Problem*

The flow to a plant is 3.40 MGD. Jar testing indicates that the optimum alum dose is 10 mg/L. What should the gpd setting be for the solution feeder if the alum solution is a 52% solution?

*Solution*

A solution concentration of 52% is equivalent to 520,000 mg/L:

$$\text{Desired dose (lb/day)} = \text{actual dose (lb/day)}$$

Referring to Equation 28.13:

$$10\ \text{mg/L} \times 3.40\ \text{MGD} \times 8.34\ \text{lb/gal} = 520{,}000\ \text{mg/L} \times x\ \text{MGD} \times 8.34\ \text{lb/gal}$$

$$x = \frac{10 \times 3.40 \times 8.34}{520{,}000 \times 8.34}$$

$$= 0.000063\ \text{MGD}$$

This can be expressed as gpd flow:

$$0.0000653 \text{ MGD} = 65.3 \text{ gpd flow}$$

## Chemical Feed Pump: Percent Stroke Setting

Chemical feed pumps are generally positive displacement pumps (also called *piston* pumps). This type of pump displaces, or pushes out, a volume of chemical equal to the volume of the piston. The length of the piston, called the *stroke*, can be lengthened or shortened to increase or decrease the amount of chemical delivered by the pump. As mentioned, each stroke of a piston pump displaces or pushes chemical out. In calculating percent stroke setting, use Equation 28.14

$$\% \text{ Stroke setting} = \frac{\text{required feed (gpd)}}{\text{maximum feed (gpd)}} \times 100 \tag{28.14}$$

### Example 28.15

*Problem*

The required chemical pumping rate has been calculated as 8 gpm. If the maximum pumping rate is 90 gpm, what should the percent stroke setting be?

*Solution*

The percent stroke setting is based on the ratio of the gpm required to the total possible gpm:

$$\% \text{ Stroke setting} = \frac{\text{required feed (gpd)}}{\text{maximum feed (gpd)}} \times 100$$

$$= \frac{8 \text{ gpm}}{90 \text{ gpm}} \times 100$$

$$= 8.9\%$$

## Chemical Solution Feeder Setting (mL/min)

Some chemical solution feeders dispense chemical as milliliters per minute (mL/min). To calculate the mL/min solution required, use the following equation:

$$\text{Solution (mL/min)} = \frac{\text{gpd} \times 3785 \text{ mL/gal}}{1440 \text{ min/day}} \tag{28.15}$$

### Example 28.16

*Problem*

The desired solution feed rate was calculated to be 7 gpd. What is this feed rate (expressed as mL/min)?

*Solution*

Because the gpd flow has already been determined, the mL/min flow rate can be calculated directly:

$$\text{Feed rate (mL/min)} = \frac{\text{gpd} \times 3785 \text{ mL/gal}}{1440 \text{ min/day}}$$

$$= \frac{7 \text{ gpd} \times 3785 \text{ mL/gal}}{1440 \text{ min/day}}$$

$$= 18 \text{ mL/min feed rate}$$

## Chemical Feed Calibration

Routinely, to ensure accuracy, we need to compare the actual chemical feed rate with the feed rate indicated by the instrumentation. To accomplish this, we use calibration calculations. To calculate the actual chemical feed rate for a dry chemical feed, place a container under the feeder, weigh the container when empty, and then weigh the container again after a specified length of time, such as 30 minutes. Then actual chemical feed rate can then be determined as:

$$\text{Chemical feed rate } (\text{lb/min}) = \frac{\text{chemical applied (lb)}}{\text{length of application (min)}} \tag{28.16}$$

### Example 28.17

*Problem*

Calculate the actual chemical feed rate (lb/day) if a container is placed under a chemical feeder and a total of 2.2 lb is collected during a 30-minute period.

*Solution*

First calculate the lb/min feed rate using Equation 28.16:

$$\text{Chemical feed rate } (\text{lb/min}) = \frac{2.2 \text{ lb}}{30 \text{ min}}$$

$$= 0.07 \text{ lb/min}$$

Then calculate the lb/day feed rate:

$$\text{Chemical feed rate } (\text{lb/day}) = 0.07 \text{ lb/min} \times 1440 \text{ min/day}$$

$$= 101 \text{ lb/day}$$

### Example 28.18

*Problem*

A chemical feeder must be calibrated. The container to be used to collect chemical is placed under the chemical feeder and weighed (0.35 lb). After 30 minutes, the weight of the container and chemical is found to be 2.2 lb. Based on this test, what is the actual chemical feed rate (in lb/day)?

*Solution*

First calculate the lb/min feed rate using Equation 28.16.

> **Key Point:** The chemical applied is the weight of the container and chemical minus the weight of the empty container.

$$\text{Chemical feed rate } (\text{lb/min}) = \frac{2.2 \text{ lb} - 0.35 \text{ lb}}{30 \text{ minutes}}$$

$$= \frac{1.85 \text{ lb}}{30 \text{ minutes}}$$

$$= 0.062 \text{ lb/min}$$

Then calculate the lb/day feed rate:

$$0.062 \text{ lb/min} \times 1440 \text{ min/day} = 89 \text{ lb/day feed rate}$$

When the chemical feeder is for a solution, the calibration calculation is slightly more difficult than that for a dry chemical feeder. As with other calibration calculations, the actual chemical feed rate is determined and then compared with the feed rate indicated by the instrumentation. The calculations used for solution feeder calibration are as follows:

$$\text{Flow rate (gpd)} = \frac{\text{mL/min} \times 1440 \text{ min/day}}{3785 \text{ mL/gal}} = \text{gpd} \tag{28.17}$$

Then calculate chemical dosage (lb/day):

$$\text{Chemical (lb/day)} = \text{Chemical (mg/L)} \times \text{flow (MGD)} \times 8.34 \text{ lb/day} \tag{28.18}$$

**Example 28.19**

*Problem*

A calibration test is conducted for a solution chemical feeder. During 5 minutes, the solution feeder delivers a total of 700 mL. The polymer solution is a 1.3% solution. What is the lb/day feed rate? (Assume the polymer solution weighs 8.34 lb/gal.)

*Solution*

The mL/min flow rate is calculated as:

$$\frac{700 \text{ mL}}{5 \text{ min}} = 140 \text{ mL/min}$$

Then convert the mL/min flow rate to a gpd flow rate:

$$\frac{140 \text{ mL/min} \times 1440 \text{ min/day}}{3785 \text{ mL/gal}} = 53 \text{ gpd flow rate}$$

and calculate the lb/day feed rate:

$$\text{Chemical (mg/L)} \times \text{flow (MGD)} \times 8.34 \text{ lb/day} = \text{chemical (lb/day)}$$

$$\text{Feed rate (lb/d)} = 13{,}000 \text{ mg/L} \times 0.000053 \text{ MGD} \times 8.34 \text{ lb/day} = 5.7 \text{ lb/day}$$

Actual pumping rates can be determined by calculating the volume pumped during a specified timeframe. For example, if 120 gallons are pumped during a 15-minute test, the average pumping rate during the test is 8 gpm.

The gallons pumped can be determined by measuring the drop in tank level during the timed test:

$$\text{Flow (gpm)} = \frac{\text{volume pumped (gal)}}{\text{duratin of test (min)}} \tag{28.19}$$

Then the actual flow rate (gpm) is calculated using:

$$\text{Flow rate (gpm)} = \frac{0.785 \times D^2 \times \text{drop in level (ft)} \times 7.48\ \text{gal/ft}^3}{\text{duration of test (min)}} \tag{28.20}$$

**Example 28.20**

*Problem*

A pumping rate calibration test is conducted for a 5-minute period. The liquid level in the 4-ft-diameter solution tank is measured before and after the test. If the level drops 0.4 ft during the 5-min test, what is the pumping rate in gpm?

*Solution*

Referring to Equation 28.20,

$$\text{Flow rate (gpm)} = \frac{0.785 \times \text{D}^2 \times \text{drop (ft)} \times 7.48\ \text{gal/cu ft}}{\text{duration of test (min)}}$$

$$= \frac{0.785 \times 4\ \text{ft} \times 4\ \text{ft} \times 0.4\ \text{ft} \times 7.48\ \text{gal/cu ft}}{5\ \text{min}}$$

$$\text{Pumping rate} = 7.5\ \text{gpm}$$

## Average Use Calculations

During a typical shift, operators log in or record several parameter readings. The data collected are important in monitoring plant operation as they provide information on how best to optimize plant or unit process operation. One of the important parameters monitored each shift or each day is actual use of chemicals. From the recorded chemical use data, expected chemical use forecasts can be made. Such data are also important for inventory control, as far as determining when additional chemical supplies will be required. To determine average chemical use, we first must determine the average chemical use:

$$\text{Average use (lb/day)} = \frac{\text{total chemical used (lb)}}{\text{number of days}} \tag{28.21}$$

or

$$\text{Average use (gpd)} = \frac{\text{total chemical used (gal)}}{\text{number of days}} \tag{28.22}$$

Then calculate the number of days worth of supply in inventory:

$$\text{Inventory supply (day)} = \frac{\text{total chemical in inventory (lb)}}{\text{average use (lb/day)}} \tag{28.23}$$

or

$$\text{Inventory supply (day)} = \frac{\text{total chemical in inventory (gal)}}{\text{average use (gpd)}} \tag{28.24}$$

**Example 28.21**

*Problem*

The amount of chemical used each day for a week is given below. Based on the data, what was the average chemical use (in lb/day) during the week?

| | |
|---|---|
| Monday, 92 lb/day | Friday, 96 lb/day |
| Tuesday, 94 lb/day | Saturday, 92 lb/day |
| Wednesday, 92 lb/day | Sunday, 88 lb/day |
| Thursday, 88 lb/day | |

*Solution*

Referring to Equation 28.21,

$$\text{Average use (lb/day)} = \frac{642 \text{ lb}}{7 \text{ days}}$$

$$= 91.7 \text{ lb/day}$$

**Example 28.22**

*Problem*

The average chemical use at a plant is 83 lb/day. If the chemical inventory in stock is 2600 lb, how many days' supply is this?

*Solution*

Referring to Equation 28.23,

$$\text{Inventory supply (day)} = \frac{2600 \text{ lb in inventory}}{83 \text{ lb/day average use}}$$

$$= 31.3 \text{ days}$$

# 29 Biosolids Production and Pumping Calculations

### TOPICS



### PROCESS RESIDUALS

The wastewater unit treatment processes remove solids and biochemical oxygen demand (BOD) from the waste stream before the liquid effluent is discharged to its receiving waters. What remains to be disposed of is a mixture of solids and wastes, called *process residuals* (more commonly referred to as *biosolids* or *sludge*).

> ✔ **Key Point:** *Sludge* is the commonly accepted name for wastewater residual solids; however, if wastewater sludge is used for beneficial reuse (e.g., as a soil amendment or fertilizer), it is commonly referred to as *biosolids*. We choose to refer to process residuals as biosolids in this text.

The most costly and complex aspect of wastewater treatment can be the collection, processing, and disposal of biosolids. This is the case because the quantity of biosolids produced may be as high as 2% of the original volume of wastewater, depending somewhat on the treatment process being used. Because the 2% biosolids can be as much as 97% water content and because cost of disposal will be related to the volume of biosolids being processed, one of the primary purposes or goals (along with stabilizing it so it is no longer objectionable or environmentally damaging) of biosolids treatment is to separate as much of the water from the solids as possible.

### PRIMARY AND SECONDARY SOLIDS PRODUCTION CALCULATIONS

It is important to point out that when making calculations pertaining to solids and biosolids, the term *solids* refers to dry solids and the term *biosolids* refers to the solids and water. The solids produced during primary treatment depend on the solids that settle in, or are removed by, the primary clarifier (see Figure 29.1). To make primary clarifier solids production calculations, we use the mg/L to lb/day equation:

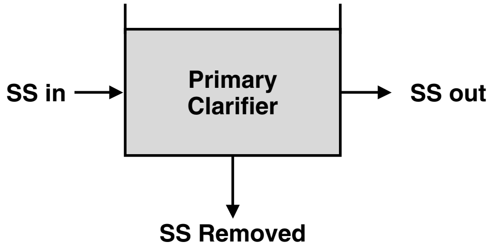


**FIGURE 29.1** Solids in and out of a primary clarifier.

$$\text{Suspended solids (SS) removed (lb/day)} = \text{SS removed (mg/L)} \times \text{flow (MGD)} \times 8.34 \text{ lb/gal} \quad (29.1)$$

## Primary Clarifier Solids Production Calculations

### Example 29.1

*Problem*

A primary clarifier receives a flow of 1.80 MGD with suspended solids concentrations of 340 mg/L. If the clarifier effluent has a suspended solids concentration of 180 mg/L, how many pounds of solids are generated daily?

*Solution*

Referring to Equation 29.1,

$$\text{SS removed (lb/d)} = 160 \text{ mg/L} \times 1.80 \text{ MGD} \times 8.34 \text{ lb/gal}$$

$$= 2402 \text{ lb/day}$$

### Example 29.2

*Problem*

The suspended solids content of the primary influent is 350 mg/L and the primary influent is 202 mg/L. How many pounds of solids are produced during a day when the flow is 4,150,000 gpd?

*Solution*

Again referring to Equation 29.1:

$$\text{SS removed (lb/d)} = 148 \text{ mg/L} \times 4.15 \text{ MGD} \times 8.34 \text{ lb/gal}$$

$$= 5122 \text{ lb/day}$$

## Secondary Clarifier Solids Production Calculations

Solids produced during secondary treatment depend on many factors, including the amount of organic matter removed by the system and the growth rate of the bacteria (see Figure 29.2). Because precise calculations of biosolids production is complex, we use a rough estimate method of solids production that uses an estimated growth rate (unknown) value. The BOD removed (lb/day) equation is shown below:

$$\text{BOD removed (lb/day)} = \text{BOD removed (mg/L)} \times \text{flow (MGD)} \times 8.34 \text{ lb/day} \quad (29.2)$$

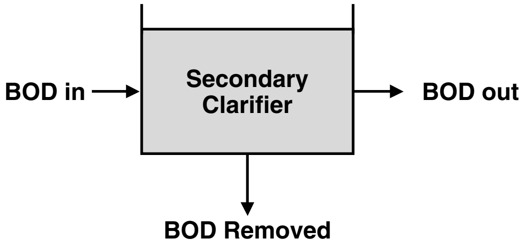


**FIGURE 29.2** Solids produced during secondary treatment.

### Example 29.3

*Problem*

The 1.5-MGD influent to the secondary system has a BOD concentration of 174 mg/L. The secondary effluent contains 22 mg/L BOD. If the bacteria growth rate (unknown $x$ value) for this plant is 0.40 lb SS per lb BOD removed, how many pounds of dry biosolids solids are produced each day by the secondary system?

*Solution*

Referring to Equation 29.2:

$$\text{BOD removed (lb/day)} = 152 \text{ mg/L} \times 1.5 \text{ MGD} \times 8.34 \text{ lb/gal}$$

$$= 1902 \text{ lb/day}$$

Then use the unknown $x$ value to determine the lb/day solids produced:

$$\frac{0.44 \text{ lb SS produced}}{1 \text{ lb BOD removed}} = \frac{x \text{ lb SS produced}}{1902 \text{ lb/day BOD removed}}$$

$$x = \frac{0.44 \times 1902}{1}$$

$$= 837 \text{ lb/day solids produced}$$

**Key Point:** Typically, for every pound of food consumed (BOD removed) by the bacteria, between 0.3 and 0.7 lb of new bacteria cells is produced; these are solids that have to be removed from the system.

## PERCENT SOLIDS

Biosolids is composed of water and solids. The vast majority of biosolids is water, usually in the range of 93 to 97% (see Figure 29.3). To determine the solids content of a biosolids, a sample of biosolids is dried overnight in an oven at 103 to 105°F. The solids that remain after drying represent the total solids content of the biosolids. Solids content may be expressed as a percent or as mg/L. Either of two equations is used to calculate percent solids:

$$\% \text{ Solids} = \frac{\text{total solids (g)}}{\text{biosolids sample (g)}} \times 100 \tag{29.3}$$

$$\% \text{ Solids} = \frac{\text{solids (lb/day)}}{\text{biosolids (lb/day)}} \times 100 \tag{29.4}$$

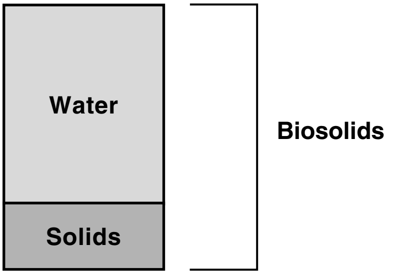


**FIGURE 29.3** Composition of biosolids.

### Example 29.4

*Problem*
The total weight of a biosolids sample (sample only, not the dish) is 22 grams. If the weight of the solids after drying is 0.77 grams, what is the percent total solids of the biosolids?

*Solution*
Referring to Equation 29.3:

$$\%\ \text{Solids} = \frac{0.77\ \text{g}}{22\ \text{g}} \times 100$$

$$= 3.5\%$$

## BIOSOLIDS PUMPING

While on shift, wastewater operators are often required to make various process control calculations. An important calculation involves biosolids pumping. The biosolids pumping calculations the operator may be required to make are covered in this section.

### Estimating Daily Biosolids Production

The calculation for estimation of the required biosolids pumping rate provides a method to establish an initial pumping rate or evaluate the adequacy of the current withdrawal rate:

$$\text{Estimated pump rate} = \frac{(\text{influent TSS concentration} - \text{effluent TSS concentration}) \times \text{flow} \times 8.34\ \text{lb/gal}}{\%\ \text{solids in sludge} \times 8.34\ \text{lb/gal} \times 1440\ \text{min/day}} \tag{29.5}$$

### Example 29.5

*Problem*
The biosolids withdrawn from a primary settling tank contain 1.4% solids. The unit influent contains 285 mg/L TSS and the effluent contains 140 mg/L TSS. If the influent flow rate is 5.55 MGD, what is the estimated biosolids withdrawal rate in gallons per minute (assuming the pump operates continuously)?

*Solution*
Referring to Equation 29.5:

$$\text{Biosolids rate (gpm)} = \frac{(285\ \text{mg/L} - 140\ \text{mg/L}) \times 5.55 \times 8.34}{0.014 \times 8.34 \times 1440\ \text{min/day}} = 40\ \text{gpm}$$

### Biosolids Production in Pounds/Million Gallons

A common method of expressing biosolids production is in pounds of biosolids per million gallons of wastewater treated:

$$\text{Biosolids (lb/MG)} = \frac{\text{total biosolids production (lb)}}{\text{total wastewater flow (MG)}} \tag{29.6}$$

**Example 29.6**

*Problem*

Records show that a plant produced 85,000 gallons of biosolids over the past 30 days. The average daily flow for this period was 1.2 MGD. What was the biosolids production of the plant (in pounds per million gallons)?

*Solution*

$$\text{Biosolids (lb/MG)} = \frac{85{,}000\ \text{gal} \times 8.34\ \text{lb/gal}}{1.2\ \text{MGD} \times 30\ \text{day}} = 19{,}692\ \text{lb/MG}$$

### Biosolids Production in Wet Tons/Year

Biosolids production can also be expressed in terms of the amount of biosolids (water and solids) produced per year. This is normally expressed in wet tons per year.

$$\text{Biosolids (wet ton/year)} = \frac{\text{biosolids production (lb/MG)} \times \text{average daily flow (MGD)} \times 365\ \text{days/year}}{2000\ \text{lb/ton}} \tag{29.7}$$

**Example 29.7**

*Problem*

A plant is currently producing biosolids at the rate of 16,500 lb/MG. The current average daily wastewater flow rate is 1.5 MGD. What will be the total amount of biosolids produced per year (in wet tons per year)?

*Solution*

Referring to Equation 29.7:

$$\text{Biosolids (wet tons/yr)} = \frac{16{,}500\ \text{lb/MG} \times 1.5\ \text{MGD} \times 365\ \text{days/year}}{2000\ \text{lb/ton}}$$

$$= 4517\ \text{wet tons/year}$$

### Biosolids Pumping Time

The biosolids pumping time is the total time the pump operates during a 24-hour period in minutes:

$$\text{Pump operating time} = \text{time/cycle (min)} \times \text{frequency (cycles/day)} \tag{29.8}$$

*Note:* The following information is used for Example 29.8 to Example 29.13.

Frequency = 24 times/day
Pump Rate = 120 gpm
Solids = 3.70%
Volatile matter = 66%

#### Example 29.8

*Problem*
What is the pump operating time?

*Solution*
Referring to Equation 29.8:

$$\text{Pump operating time} = 15\text{ min/hour} \times 24\text{ (cycles/day)} = 360\text{ min/day}$$

#### Biosolids Pumped/Day in Gallons

$$\text{Biosolids (gpd)} = \text{operating time (min/day)} \times \text{pump rate (gpm)} \tag{29.9}$$

#### Example 29.9

*Problem*
What is the biosolids pumped per day in gallons?

*Solution*
Referring to Equation 29.9:

$$\text{Biosolids (gpd)} = 360\text{ min/day} \times 120\text{ gpm} = 43{,}200\text{ gpd}$$

#### Biosolids Pumped/Day in Pounds

$$\text{Sludge (lb/day)} = \text{Biosolids pumped (gal/d)} \times 8.34\text{ lb/gal} \tag{29.10}$$

#### Example 29.10

*Problem*
What amount of biosolids is pumped per day in pounds?

*Solution*
Referring to Equation 29.10:

$$\text{Biosolids (lb/day)} = 43{,}200\text{ gal/day} \times 8.34\text{ lb/gal} = 360{,}300\text{ lb/day}$$

#### Solids Pumped/Day in Pounds

$$\text{Solids pumped (lb/day)} = \text{biosolids pumped (lb/day)} \times \%\text{ solids}$$

**Example 29.11**

*Problem*

What are the solids pumped per day?

*Solution*

Referring to Equation 29.11:

$$\text{Solids pumped (lb/day)} = 360{,}300 \text{ lb/day} \times 0.0370 = 13{,}331 \text{ lb/day}$$

### Volatile Matter Pumped/Day in Pounds

$$\text{Volatile matter (lb/day)} = \text{solids pumped (lb/day)} \times \% \text{ volatile matter} \tag{29.11}$$

**Example 29.12**

*Problem*

What is the volatile matter in pounds per day?

*Solution*

Referring to Equation 29.11:

$$\text{Volatile matter (lb/day)} = 13{,}331 \text{ lb/day} \times 0.66 = 8798 \text{ lb/day}$$

### Pounds of Solids/Pounds of Volatile Solids per Day

If we wish to calculate the pounds of solids or the pounds of volatile solids removed per day, the individual equations demonstrated above can be combined into a single calculation.

$$\text{Solids}\left(\text{lb/day}\right) =$$

$$\text{pump time}\left(\text{min/cycle}\right) \times \text{frequency}\left(\text{cycles/day}\right) \times \text{rate}\left(\text{gpm}\right) \times 8.34 \text{ lb/gal} \times \% \text{ solids}$$

$$\text{Volatile matter}\left(\text{lb/day}\right) =$$

$$\text{time}\left(\text{min/cycle}\right) \times \text{frequency}\left(\text{cycles/day}\right) \times \text{rate}\left(\text{gpm}\right) \times 8.34 \times \% \text{ solids} \times \% \text{ VM}$$

**Example 29.13**

*Problem*

What are the solids and volatile solids removed per day?

*Solution*

Referring to Equation 29.12:

$$\begin{aligned}\text{Solids (lb/day)} &= 15 \text{ min/cycle} \times 24 \text{ cycles/day} \times 120 \text{ gpm} \times 8.34 \text{ lb/gal} \times 0.0370\\ &= 13{,}331 \text{ lb/day}\end{aligned}$$

$$\begin{aligned}\text{VM (lb/day)} &= 15 \text{ min/cycle} \times 24 \text{ cycles/day} \times 120 \text{ gpm} \times 8.34 \text{ lb/gal} \times 0.0370 \times .66\\ &= 8{,}798 \text{ lb/day}\end{aligned}$$

# 30 Biosolids Thickening Calculations

## TOPICS



## THICKENING

Biosolids thickening (or concentration) is a unit process used to increase the solids content of the biosolids by removing a portion of the liquid fraction. In other words, biosolids thickening is all about volume reduction. By increasing the solids content, more economical treatment of the biosolids can be effected. Biosolids thickening processes include the following:

- Gravity thickeners
- Flotation thickeners
- Solids concentrators

Biosolids thickening calculations are based on the concept that the solids in the primary or secondary biosolids are equal to the solids in the thickened biosolids. The solids are the same (Figure 30.1). It is primarily water that has been removed in order to thicken the biosolids and result in higher percent solids. In this unthickened biosolids, the solids might represent 1 or 4% of the total pounds of biosolids, but when some of the water is removed those same amount solids might represent 5 to 7% of the total pounds of biosolids.

> **Key Point:** The key to biosolids thickening calculations is that solids remain constant (see Figure 30.1).

## GRAVITY/DISSOLVED AIR FLOTATION THICKENER CALCULATIONS

As mentioned, biosolids thickening calculations are based on the concept that the solids in the primary or secondary biosolids are equal to the solids in the thickened biosolids. That is, assuming that a negligible amount of solids are lost in the thickener overflow, the solids are the same. Note that the water is removed to thicken the biosolids and results in higher percent solids.

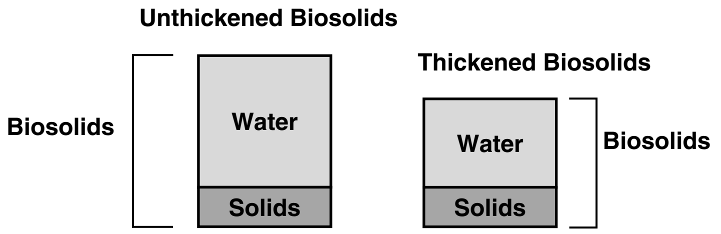


**FIGURE 30.1** Biosolids thickening = volume reduction.

## Estimating Daily Biosolids Production

The calculation for estimation of the required biosolids pumping rate provides a method for establishing an initial pumping rate or evaluating the adequacy of the current pump rate:

$$\text{Estimated pump rate} = \frac{(\text{influent TSS concentration} - \text{effluent TSS concentration}) \times \text{flow} \times 8.34 \text{ lb/gal}}{\% \text{ solids in biosolids} \times 8.34 \text{ lb/gal} \times 1440 \text{ min/day}} \tag{30.1}$$

### Example 30.1

*Problem*

The biosolids withdrawn from the primary settling tank contain 1.5% solids. The unit influent contains 280 mg/L TSS, and the effluent contains 141 mg/L TSS. If the influent flow rate is 5.55 MGD, what is the estimated biosolids withdrawal rate in gallons per minute (assuming the pump operates continuously)?

*Solution*

Referring to Equation 30.1:

$$\text{Biosolids withdrawal rate (gpm)} = \frac{(280 \text{ mg/L} - 141 \text{ mg/L}) \times 5.55 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.015 \times 8.34 \times 1440 \text{ min/day}}$$

## Surface Loading Rate (gpd/day/ft²)

The surface loading rate (surface settling rate) is hydraulic loading — the amount of biosolids applied per square foot of gravity thickener:

$$\text{Surface loading} \left(\text{gpd/day/ft}^2\right) = \frac{\text{biosolids applied to the thickener (gpd)}}{\text{thickener area} \left(\text{ft}^2\right)} \tag{30.2}$$

### Example 30.2

*Problem*

A 70-foot-diameter gravity thickener receives 32,000 gpd of biosolids. What is the surface loading in gallons per square foot per day?

*Solution*

Referring to Equation 30.2:

$$\text{Surface loading} = \frac{32,000 \text{ gpd}}{0.785 \times 70 \text{ ft} \times 70 \text{ ft}} = 8.32 \text{ gpd/ft}^2$$

### Solids Loading Rate (lb/d/ft²)

The solids loading rate is the pounds of solids per day being applied to 1 square foot of tank surface area. The calculation uses the surface area of the bottom of the tank. It assumes that the floor of the tank is flat and has the same dimensions as the surface.

$$\text{Surface loading rate} \left(\text{lb/day/ft}^2\right) = \frac{\% \text{ biosolids solids} \times \text{biosolids flow (gpd)} \times 8.34 \text{ lb/gal}}{\text{thickener area} \left(\text{ft}^2\right)} \tag{30.3}$$

**Example 30.3**

*Problem*

A thickener influent contains 1.6% solids. The influent flow rate is 39,000 gpd. The thickener is 50 ft in diameter and 10 ft deep. What is the solid loading in pounds per day?

*Solution*

Referring to Equation 30.3:

$$\text{Solids loading rate} \left(\text{lb/day/ft}^2\right) = \frac{0.016 \times 39,000 \text{ gpd} \times 8.34 \text{ lb/gal}}{0.785 \times 50 \text{ ft} \times 50 \text{ ft}} = 2.7 \text{ lb/ft}^2$$

### Concentration Factor (CF)

The concentration factor (CF) represents the increase in concentration resulting from the thickener; it is a means of determining the effectiveness of the gravity thickening process:

$$\text{Concentration factor (CF)} = \frac{\text{thickened biosolids concentration (\%)}}{\text{influent biosolids concentration (\%)}} \tag{30.4}$$

**Example 30.4**

*Problem*

The influent biosolids contains 3.5% solids. The thickened biosolids solids concentration is 7.7%. What is the concentration factor?

*Solution*

Referring to Equation 30.4:

$$\text{CF} = \frac{7.7\%}{3.5\%} = 2.2$$

### Air-to-Solids Ratio

This is the ratio between the pounds of solids entering the thickener and the pounds of air being applied:

$$\text{Air:solids ratio} = \frac{\text{air flow}\left(\text{ft}^3/\text{min}\right) \times 0.0785\ \text{lb/ft}^3}{\text{biosolids flow}\left(\text{gpm}\right) \times \%\ \text{solids} \times 8.34\ \text{lb/gal}} \tag{30.5}$$

**Example 30.5**

*Problem*

The biosolids pumped to the thickener are 0.85% solids. The airflow is 13 cubic feet per minute ($ft^3$/min). What is the air-to-solids ratio if the current biosolids flow rate entering the unit is 50 gpm?

*Solution*

Referring to Equation 30.5:

$$\text{Air:solids ratio} = \frac{13\ \text{ft}^3/\text{min} \times 0.075\ \text{lb/ft}^3}{50\ \text{gpm} \times 0.0085 \times 8.34\ \text{lb/gal}} = 0.28$$

### Recycle Flow in Percent

The amount of recycle flow is expressed as a percent:

$$\text{Recycle}\ \% = \frac{\text{recycle flow rate}\left(\text{gpm}\right) \times 100}{\text{sludge flow}\left(\text{gpm}\right)} = 175\% \tag{30.6}$$

**Example 30.6**

*Problem*

The sludge flow to the thickener is 80 gpm. The recycle flow rate is 140 gpm. What is the percent recycle?

*Solution*

Referring to Equation 30.6:

$$\%\ \text{Recycle} = \frac{140\ \text{gpm} \times 100}{80\ \text{gpm}} = 175\%$$

## CENTRIFUGE THICKENING CALCULATIONS

A centrifuge exerts a force on the biosolids thousands of times greater than gravity. Sometimes polymer is added to the influent of the centrifuge to help thicken the solids. The two most important factors that affect the centrifuge are the volume of the biosolids put into the unit (gpm) and the pounds of solids put in. The water that is removed is called *centrate*. Normally, hydraulic loading is measured as flow rate per unit of area; however, because of the variety of sizes and designs, hydraulic loading to centrifuges does not include area considerations. It is expressed only as gallons per hour. The equations to be used if the flow rate to the centrifuge is given as gallons per day or gallons per minute are:

$$\text{Hydraulic loading (gph)} = \frac{\text{flow (gpd)}}{24\ \text{hr/day}} \tag{30.7}$$

$$\text{Hydraulic loading (gph)} = \text{Flow (gpm)} \times 60\ \text{min/hr} \tag{30.8}$$

**Example 30.7**

*Problem*

A centrifuge receives a waste activated biosolids flow of 40 gpm. What is the hydraulic loading on the unit (in gal/hr)?

*Solution*

Referring to Equation 30.8:

$$\text{Hydraulic loading (gph)} = 40\ \text{gpm} \times 60\ \text{min/hr} = 2400\ \text{gph}$$

**Example 30.8**

*Problem*

A centrifuge receives 48,600 gal of biosolids daily. The biosolids concentration before thickening is 0.9%. How many pounds of solids are received each day?

*Solution*

$$\frac{48{,}600\ \text{gal}}{\text{d}} \times \frac{8.34\ \text{lb}}{\text{gal}} \times \frac{0.9}{100} = 3648\ \text{lb/d}$$

# 31 Biosolids Digestion

## TOPICS



## BIOSOLIDS STABILIZATION

A major problem in designing wastewater treatment plants is the disposal of biosolids into the environment without causing damage or nuisance. Untreated biosolids are even more difficult to dispose of. Untreated raw biosolids must be stabilized to minimize disposal problems. In many cases, the term *stabilization* is considered synonymous with digestion.

> ✔ **Key Point:** The *stabilization* of organic matter is accomplished biologically using a variety of organisms. The microorganisms convert the colloidal and dissolved organic matter into various gases and into protoplasm. Because protoplasm has a specific gravity slightly higher than that of water, it can be removed from the treated liquid by gravity.

*Biosolids digestion* is a process in which biochemical decomposition of the organic solids occurs; in the decomposition process, the organics are converted into simpler and more stable substances. Digestion also reduces the total mass or weight of biosolids solids, destroys pathogens, and makes it easier to dry or dewater the biosolids. Well-digested biosolids have the appearance and characteristics of a rich-potting soil. Biosolids may be digested under aerobic or anaerobic conditions. Most large municipal wastewater treatment plants use anaerobic digestion. Aerobic digestion finds application primarily in small, package-activated biosolids treatment systems.

## AEROBIC DIGESTION PROCESS CONTROL CALCULATIONS

The purposes of aerobic digestion are to stabilize organic matter, to reduce volume, and to eliminate pathogenic organisms. Aerobic digestion is similar to the activated biosolids process. Biosolids are aerated for 20 days or more. Volatile solids are reduced by biological activity.

### Volatile Solids Loading (lb/ft$^3$/day)

Volatile solids (organic matter) loading for the aerobic digester is expressed in pounds of volatile solids entering the digester per day per cubic foot of digester capacity:

$$\text{Volatile solids loading}\left(\text{lb/day/ft}^3\right) = \frac{\text{volatile solids added}\left(\text{lb/day}\right)}{\text{digester volume}\left(\text{ft}^3\right)} \tag{31.1}$$

**Example 31.1**

*Problem*

An aerobic digester is 20 ft in diameter and has an operating depth of 20 ft. The biosolids that are added to the digester daily contain 1500 lb of volatile solids. What is the volatile solids loading in pounds per day per cubic foot?

*Solution*

Referring to Equation 31.1:

$$\text{Volatile solids loading}\left(\text{lb/day/ft}^3\right) = \frac{1500\text{ lb/day}}{0.785 \times 20\text{ ft} \times 20\text{ ft} \times 20\text{ ft}} = 0.24\text{ lb/day/ft}^3$$

## Digestion Time (day)

The theoretical time the biosolids remain in the aerobic digester is expressed as:

$$\text{Digestion time}\left(\text{day}\right) = \frac{\text{digester volume}\left(\text{gal}\right)}{\text{biosolids added}\left(\text{gpd}\right)} \tag{31.2}$$

**Example 31.2**

*Problem*

The digester volume is 240,000 gal. Biosolids is added to the digester at the rate of 15,000 gpd. What is the digestion time in days?

*Solution*

Referring to Equation 31.2:

$$\text{Digestion time}\left(\text{day}\right) = \frac{240{,}000\text{ gal}}{15{,}000\text{ gpd}} = 16\text{ days}$$

## pH Adjustment

In many instances, the pH of the aerobic digester will fall below the levels required for good biological activity. When this occurs, the operator must perform a laboratory test to determine the amount of alkalinity required to raise the pH to the desired level. The results of the lab test must then be converted to the actual quantity required by the digester.

$$\text{Chemical required (lb)} = \frac{\text{chemical used in lab test}\left(\text{mg}\right) \times \text{digester volume} \times 3.785}{\text{sample volume}\left(\text{L}\right) \times 454\text{ g/lb} \times 1000\text{ mg/g}} \tag{31.3}$$

**Example 31.3**

*Problem*

To increase the pH of a 1-liter sample of contents of an aerobic digester to pH 7.1, 240 mg of lime are required. The digester volume is 240,000 gal. How many pounds of lime will be required to increase the digester pH to 7.3?

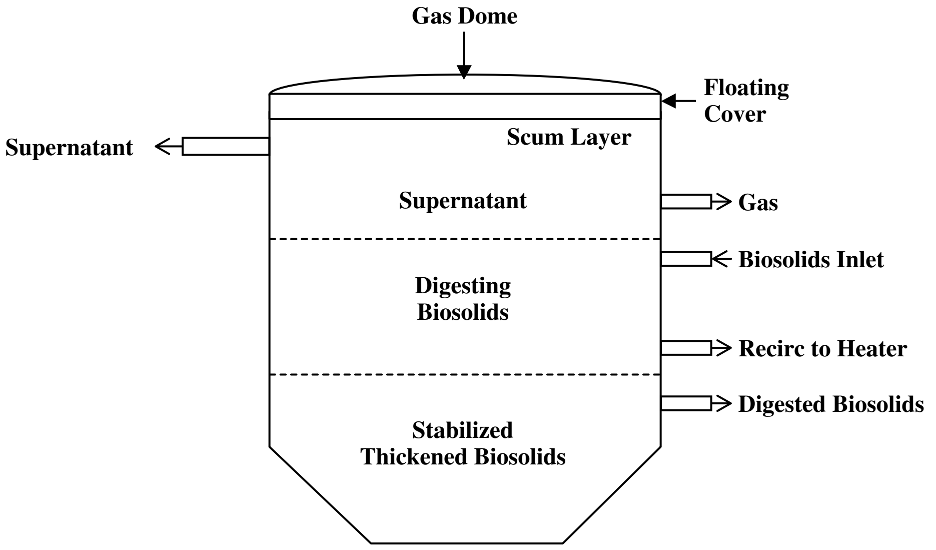


**FIGURE 31.1** Floating roof digester.

*Solution*

Referring to Equation 31.3:

$$\text{Chemical required (lb)} = \frac{240 \text{ mg} \times 240{,}000 \text{ gal} \times 3.785 \text{ L/gal}}{1 \text{ L} \times 454 \text{ g/lb} \times 1000 \text{ mg/g}}$$

## ANAEROBIC DIGESTION PROCESS CONTROL CALCULATIONS

The purposes of anaerobic digestion are the same as aerobic digestion: to stabilize organic matter, to reduce volume, and to eliminate pathogenic organisms. Equipment used in anaerobic digestion includes an anaerobic digester of either floating or fixed cover type (see Figure 31.1). These include biosolids pumps for biosolids addition and withdrawal, as well as heating equipment such as heat exchangers, heaters and pumps, and mixing equipment for recirculation. Typical ancillaries include gas storage, cleaning equipment, and safety equipment such as vacuum relief and pressure relief devices, flame traps, and explosion-proof electrical equipment. In the anaerobic process, biosolids enter the sealed digester, where organic matter decomposes anaerobically. Anaerobic digestion is a two-stage process:

- Sugars, starches, and carbohydrates are converted to volatile acids, carbon dioxide, and hydrogen sulfide.
- Volatile acids are converted to methane gas.

Key anaerobic digestion process control calculations are covered in the sections that follow.

### Required Seed Volume (gal)

$$\text{Seed volume (gallons)} = \text{digester volume (gal)} \times \% \text{ seed} \qquad (31.4)$$

### Example 31.4

*Problem*

A new digester requires 25% seed to achieve normal operation within the allotted time. If the digester volume is 280,000 gallons, how many gallons of seed material will be required?

*Solution*

Referring to Equation 31.4:

$$\text{Seed volume (gal)} = 280{,}000 \times 0.25 = 70{,}000 \text{ gal}$$

## Volatile Acids to Alkalinity Ratio

The volatile acids to alkalinity ratio can be used to control anaerobic digesters:

$$\text{Ratio} = \frac{\text{volatile acids concentration}}{\text{alkalinity concentration}} \tag{31.5}$$

### Example 31.5

*Problem*

A digester contains 240 mg/L of volatile acids and 1840 mg/L alkalinity. What is the volatile acids/alkalinity ratio?

*Solution*

Referring to Equation 31.5:

$$\text{Ratio} = \frac{240 \text{ mg/L}}{1840 \text{ mg/L}} = 0.13$$

> **Key Point:** Increases in the ratio normally indicate a potential change in the operating condition of the digester.

## Biosolids Retention Time

The length of time the biosolids remains in the digester can be expressed as:

$$\text{BRT} = \frac{\text{digester volume (gallons)}}{\text{biosolids volume added per day (gpd)}} \tag{31.6}$$

### Example 31.6

*Problem*

Biosolids are added to a 520,000-gallon digester at the rate of 12,600 gallons per day. What is the biosolids retention time?

*Solution*

Referring to Equation 31.6:

$$\text{BRT} = \frac{520{,}000 \text{ gal}}{12{,}600 \text{ gpd}} = 41.3 \text{ days}$$

## Estimated Gas Production (ft³/d)

The rate of gas production is normally expressed as the volume of gas ($ft^3$) produced per pound of volatile matter destroyed. The total cubic feet of gas a digester will produce per day can be calculated by:

$$\text{Gas production } \left(\text{ft}^3/\text{day}\right) = \text{volatile matter in } (\text{lb/day}) \times \% \text{ volatile reduction} \times \text{production rate } \left(\text{ft}^3/\text{lb}\right) \tag{31.7}$$

✓ **Key Point:** Multiplying the volatile matter added to the digester per day by the percent volatile matter reduction (in decimal percent) gives the amount of volatile matter being destroyed by the digestion process per day.

### Example 31.7

*Problem*

A digester reduces 11,500 lb of volatile matter per day. Currently, the volatile matter reduction achieved by the digester is 55%. The rate of gas production is 11.2 cubic feet of gas per pound of volatile matter destroyed.

*Solution*

Referring to Equation 31.7:

$$\text{Gas production} = 11500 \text{ lb/day} \times 0.55 \times 11.2 \text{ ft}^3/\text{lb} = 70{,}840 \text{ ft}^3/\text{day}$$

## Volatile Matter Reduction (%)

Because of the changes occurring during biosolids digestion, the calculation used to determine percent volatile matter reduction is more complicated:

$$\% \text{ Reduction} = \frac{\left(\% \text{ volatile matter}_{in} - \% \text{ volatile matter}_{out}\right) \times 100}{\left[\% \text{ volatile matter}_{in} - \left(\% \text{ volatile matter}_{in} \times \% \text{ volatile matter}_{out}\right)\right]} \tag{31.8}$$

### Example 31.8

*Problem*

Determine the percent volatile matter reduction for a digester when the raw biosolids volatile matter is 71% and digested biosolids volatile matter is 54%.

*Solution*

Referring to Equation 31.8:

$$\% \text{ Volatile matter reduction} = \frac{0.71 - 0.54}{0.71 - (0.71 \times 0.54)} = 52\%$$

## Percent Moisture Reduction in Digested Biosolids

$$\% \text{ Moisture reduction} = \frac{\left(\% \text{ moisture}_{in} - \% \text{ moisture}_{out}\right) \times 100}{\left[\% \text{ moisture}_{in} - \left(\% \text{ moisture}_{in} \times \% \text{ moisture}_{out}\right)\right]} \tag{31.9}$$

✓ **Key Point:** % Moisture = 100% – percent solids.

### Example 31.9

*Problem*

Using the digester data provided below, determine the percent moisture reduction and percent volatile matter reduction for the digester.

- Raw biosolids
  - Solids, 9%
  - Moisture, 100% – 9% = 91%
- Digested biosolids
  - Solids, 15%
  - Moisture, 100% – 15% = 85%

*Solution*

Referring to Equation 31.9:

$$\%\text{ Moisture reduction} = \frac{(0.91 - 0.85) \times 100}{\left[0.91 - (0.91 \times 0.85)\right]} = 44\%$$

# 32 Biosolids Dewatering and Disposal

**TOPICS**



## BIOSOLIDS DEWATERING

The process of removing enough water from liquid biosolids to change the consistency to that of a damp solid is called *biosolids dewatering*. Although the process is also called *biosolids drying*, dry or dewatered biosolids may still contain a significant amount of water, often as much as 70%. But, at moisture contents of 70% or less, the biosolids no longer behave as a liquid and can be handled manually or mechanically. Several methods are available to dewater biosolids. The particular types of dewatering techniques or devices used best describe the actual processes used to remove water from biosolids and change their form from a liquid to damp solid. The commonly used techniques and devices include the following:

- Filter presses
- Vacuum filtration
- Sand drying beds

**Key Point:** Centrifugation is also used in the dewatering process; however, in this text we concentrate on those unit processes listed above that are traditionally used for biosolids dewatering.

Note that an ideal dewatering operation would capture all of the biosolids at minimum cost and the resultant dry biosolids solids or cake would be capable of being handled without causing unnecessary problems. Process reliability, ease of operation, and compatibility with the plant environment would also be optimized.

## PRESSURE FILTRATION CALCULATIONS

In *pressure filtration*, the liquid is forced through the filter media by a positive pressure. Several types of presses are available, but the most commonly used types are plate and frame presses and belt presses.

### PLATE AND FRAME PRESS

The *plate and frame press* consists of vertical plates that are held in a frame and pressed together between a fixed and moving end. A cloth filter medium is mounted on the face of each individual plate. The press is closed, and biosolids are pumped into the press at pressures up to 225 psi. They pass through feed holes in the trays along the length of the press. Filter presses usually require a precoat material, such as incinerator ash or diatomaceous earth, to aid in solids retention on the cloth and to allow easier release of the cake. Performance factors for plate and frame presses include feed biosolids characteristics, type and amount of chemical conditioning, operating pressures, and the type and amount of precoat. Filter press calculations (and other dewatering calculations) typically used in wastewater solids handling operations include solids loading rate, net filter yield, hydraulic loading rate, biosolids feed rate, solids loading rate, flocculant feed rate, flocculant dosage, total suspended solids, and percent solids recovery.

#### Solids Loading Rate

The solids loading rate is a measure of the pounds of solids applied per hour per square foot of plate area, as shown in Equation 32.1.

$$\text{Solids loading rate}\left(\text{lb/hr/ft}^2\right)=\frac{\text{biosolids (gph)}\times 8.34\ (\text{lb/gal})\times(\%\ \text{solids}/100)}{\text{plate area (sq ft)}} \tag{32.1}$$

#### Example 32.1

*Problem*

A filter press used to dewater digested primary biosolids receives a flow of 710 gallons during a 2-hr period. The biosolids have a solids content of 3.3%. If the plate surface area is 120 sq ft, what is the solids loading rate (in lb/hr/sq ft)?

*Solution*

The flow rate is given as gallons per 2 hours. First express this flow rate as gallons per hour: 710 gal/2 hr = 355 gal/hr. Referring to Equation 32.1:

$$\text{Solids loading rate (lb/hr/sq ft)}=\frac{355\ \text{gph}\times 8.34\ \text{lb/gal}\times\dfrac{3.3}{100}}{120\ \text{sq ft}}$$

$$= 0.81\ \text{lb/hr/sq ft}$$

> **Key Point:** The solids loading rate measures the pounds per hour of solids applied to each square foot of plate surface area; however, this does not reflect the time when biosolids feed to the press is stopped.

#### Net Filter Yield

Operated in the batch mode, biosolids are fed to the plate and frame filter press until the space between the plates is completely filled with solids. The biosolids flow to the press is then stopped

and the plates are separated, allowing the biosolids cake to fall into a hopper or conveyor below. The *net filter yield* (measured in lb/hr/sq ft), reflects the run time as well as the down time of the plate and frame filter press. To calculate the net filter yield, simply multiply the solids loading rate (in lb/hr/sq ft) by the ratio of filter run time to total cycle time as follows:

$$\text{Net filter yield} = \frac{\left[\text{biolsolids (gph)} \times 8.34 \text{ lb/gal} \times \% \text{ solids}/100\right]}{\text{plate area (sq ft)}} \times \frac{\text{filter run time}}{\text{total cycle time}} \tag{32.2}$$

### Example 32.2

*Problem*

A plate and frame filter press receives a flow of 660 gallons of biosolids during a 2-hour period. The solids concentration of the biosolids is 3.3%. The surface area of the plate is 110 sq ft. If the down time for biosolids cake discharge is 20 minutes, what is the net filter yield (in lb/hr/sq ft)?

*Solution*

First, calculate the solids loading rate, then multiply that number by the corrected time factor using Equation 32.1:

$$\text{Solids loading rate} = \frac{\left[330 \text{ gph} \times 8.34 \text{ lb/gal} \times (3.3/100)\right]}{100 \text{ sq ft}}$$

$$= 0.83 \text{ lb/hr/sq ft}$$

Next, calculate the net filter yield, using the corrected time factor:

$$\text{Net filter yield (lb/hr/sq ft)} = \frac{0.83 \text{ lb/hr/sq ft} \times 2 \text{ hr}}{2.33 \text{ hr}}$$

$$= 0.71 \text{ lb/hr/sq ft}$$

## Belt Filter Press

The *belt filter press* consists of two porous belts. The biosolids are sandwiched between the two porous belts (see Figure 32.1). The belts are pulled tight together as they are passed around a series of rollers to squeeze water out of the biosolids. Polymer is added to the biosolids just before it gets to the unit. The biosolids are then distributed across one of the belts to allow for some of the water to drain by gravity. The belts are then put together with the biosolids in between.

### Hydraulic Loading Rate

The hydraulic loading for belt filters is a measure of gpm flow per foot or belt width (Figure 32.2):

$$\text{Hydraulic loading rate (gpm/ft)} = \frac{\text{flow (gpm)}}{\text{belt width (ft)}} \tag{32.3}$$

### Example 32.3

*Problem*

A 6-foot-wide belt press receives a flow of 110 gpm of primary biosolids. What is the hydraulic loading rate (in gpm/ft)?

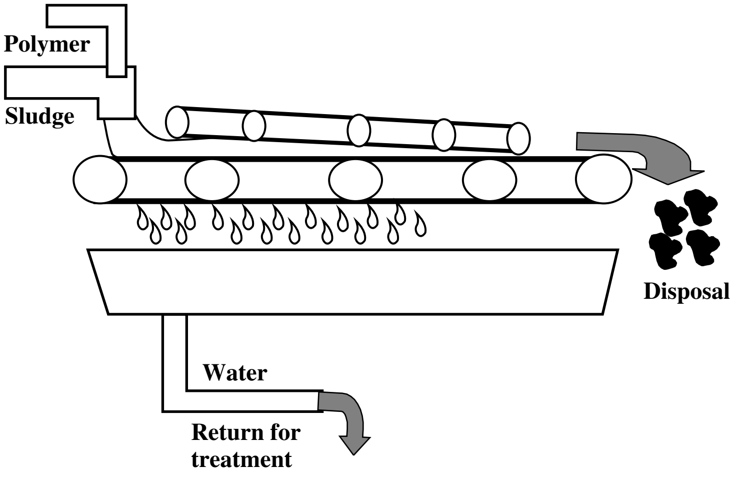


**FIGURE 32.1** Belt filter press.

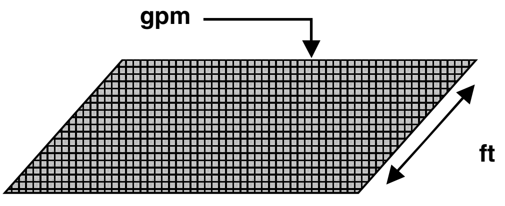


**FIGURE 32.2** Belt filter hydraulic loading rate.

*Solution*

Referring to Equation 32.3:

$$\text{Hydraulic loading rate (gpm/ft)} = \frac{110 \text{ gpm}}{6 \text{ ft}}$$

$$= 18.3 \text{ gpm/ft}$$

**Example 32.4**

*Problem*

A belt filter press that is 5 ft wide receives a primary biosolids flow of 150 gpm. What is the hydraulic loading rate (in gpm/sq ft)?

*Solution*

Referring to Equation 32.3:

$$\text{Hydraulic loading rate (gpm/ft)} = \frac{150 \text{ gpm}}{5 \text{ ft}}$$

$$= 30 \text{ gpm/ft}$$

### Biosolids Feed Rate

The biosolids feed rate to the belt filter press depends on several factors, including the biosolids (lb/d) that must be dewatered, the maximum solids feed rate (lb/hr) that will produce an acceptable cake dryness, and the number of hours per day the belt press is in operation. The equation used in calculating biosolids feed rate is:

$$\text{Biosolids feed rate}\left(\text{lb/hr}\right) = \frac{\text{biosolids to be dewatered}\left(\text{lb/day}\right)}{\text{operating time}\left(\text{hr/day}\right)} \tag{32.4}$$

### Example 32.5

*Problem*

The amount of biosolids to be dewatered by the belt filter press is 20,600 lb/day. If the belt filter press is to be operated 10 hours each day, what should be the biosolids feed rate to the press (in lb/hr)?

*Solution*

Referring to Equation 32.4:

$$\text{Biosolids feed rate}\left(\text{lb/hr}\right) = \frac{20{,}600\ \text{lb/day}}{10\ \text{hr/day}}$$

$$= 2060\ \text{lb/hr}$$

### Solids Loading Rate

The solids loading rate may be expressed as pounds per hour (lb/hr) or as tons per hour (ton/hr). In either case, the calculation is based on biosolids flow (or feed) to the belt press and percent of mg/L concentration of total suspended solids (TSS) in the biosolids. The equation used to calculate the solids loading rate is

$$\text{Solids loading rate (lb/hr)} = \text{Feed (gpm)} \times 60\ \text{min/hr} \times 8.34\ \text{lb/gal} \times (\%\text{TSS}/100) \tag{32.5}$$

### Example 32.6

*Problem*

The biosolids feed to a belt filter press is 120 gpm. If the total suspended solids concentration of the feed is 4%, what is the solids loading rate (in lb/hr)?

*Solution*

Referring to Equation 32.5:

$$\text{Solids loading rate (lb/hr)} = 120\ \text{gpm} \times 60\ \text{min/hr} \times 8.34\ \text{lb/gal} \times (4/100)$$

$$= 2402\ \text{lb/hr}$$

### Flocculant Feed Rate

The flocculant feed rate may be calculated in the same way as for all other mg/L to lb/day calculations and then converted to a lb/hr feed rate, as follows:

$$\text{Flocculant feed (lb/day)} = \frac{\text{flocculants (mg/L)} \times \text{feed rate (MGD)} \times 8.34 \text{ lb/gal}}{24 \text{ hr/day}} \tag{32.6}$$

### Example 32.7

*Problem*

The flocculant concentration for a belt filter press is 1% (10,000 mg/L). If the flocculant feed rate is 3 gpm, what is the flocculant feed rate (in lb/hr)?

*Solution*

First calculate lb/d flocculant using the mg/L to lb/day calculation. Note that the gpm feed flow must first be expressed as MGD feed flow:

$$\frac{3 \text{ gpm} \times 1440 \text{ min/day}}{1,000,000} = 0.00432 \text{ MGD}$$

Referring to Equation 32.6:

$$\text{Flocculant feed (lb/day)} = 10,000 \text{ mg/L} \times 0.00432 \text{ MGD} \times 8.34 \text{ lb/gal}$$

$$= 360 \text{ lb/day}$$

Then we can convert lb/day flocculants to lb/hr:

$$\frac{360 \text{ lb/day}}{24 \text{ hr/day}} = 15 \text{ lb/hr}$$

## Flocculant Dosage

Once the solids loading rate (ton/hr) and flocculant feed rate (lb/hr) have been calculated, the flocculant dose in lb/ton can be determined. The equation used to determine flocculant dosage is:

$$\text{Flocculant dosage (lb/ton)} = \frac{\text{flocculant (lb/hr)}}{\text{solids treated (ton/hr)}} \tag{32.7}$$

### Example 32.8

*Problem*

A belt filter has solids loading rate of 3100 lb/hr and a flocculant feed rate of 12 lb/hr. Calculate the flocculant dose in lb per ton of solids treated.

*Solution*

First, convert lb/hr solids loading to ton/hr solids loading:

$$\text{Solids loading (ton/hr)} = \frac{3100 \text{ lb/hr}}{2000 \text{ lb/ton}} = 1.55 \text{ ton/hr}$$

Now calculate lb flocculant per ton of solids treated using Equation 32.7:

$$\text{Flocculant dosage (lb/ton)} = \frac{12 \text{ lb/hr}}{1.55 \text{ tons/hr}}$$

$$= 7.8 \text{ lb/ton}$$

### Total Suspended Solids

The feed biosolids solids are comprised of two types of solids: suspended solids and dissolved solids (see Figure 32.3):

- *Suspended solids* will not pass through a glass fiber filter pad and can be further classified as total suspended solids (TSS), volatile suspended solids, and/or fixed suspended solids. They can also be separated into three components based on settling characteristics: settleable solids, floatable solids, and colloidal solids. Total suspended solids in wastewater normally fall in the range of 100 to 350 mg/L.
- *Dissolved solids* will pass through a glass fiber filter pad and can also be classified as total dissolved solids (TDS), volatile dissolved solids, and fixed dissolved solids. Total dissolved solids are normally in the range of 250 to 850 mg/L.

Two lab tests can be used to estimate the total suspended solids concentration of the feed biosolids concentration of the feed biosolids to the filter press: *total residue test* (measures both suspended and dissolved solids concentrations) and *total filterable residue test* (measures only the dissolved solids concentration). By subtracting the total filterable residue from the total residue, we obtain the total nonfilterable residue (total suspended solids):

$$\text{Total residue (mg/L)} - \text{total filterable residue (mg/L)} = \text{Total nonfilterable residue (mg/L)} \quad (32.8)$$

### Example 32.9

*Problem*

Lab tests indicate that the total residue portion of a feed biosolids sample is 22,000 mg/L. The total filterable residue is 720 mg/L. On this basis, what is the estimated total suspended solids concentration of the biosolids sample?

*Solution*

Referring to Equation 32.8:

$$22{,}000 \text{ mg/L} - 720 \text{ mg/L} = 21{,}280 \text{ mg/L total SS}$$

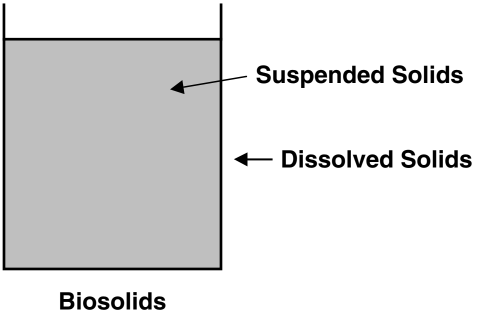


**FIGURE 32.3** Feed biosolids solids.

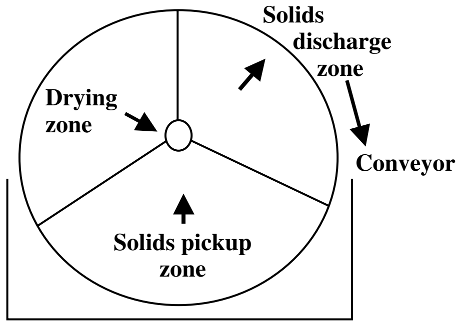


**FIGURE 32.4** Vacuum filter.

## ROTARY VACUUM FILTER DEWATERING CALCULATIONS

The *rotary vacuum filter* (see Figure 32.4) is a device used to separate solid material from liquid. The vacuum filter consists of a large drum with large holes in it covered with a filter cloth. The drum is partially submerged and rotated through a vat of conditioned biosolids. It is capable of excellent solids capture, and high-quality supernatant/filtrate solids concentrations of 15 to 40% can be achieved.

### Filter Loading

The filter loading for vacuum filters is a measure of lb/hr of solids applied per square foot of drum surface area. The equation to be used in this calculation is shown below.

$$\text{Filter loading (lb/hr/sq ft)} = \frac{\text{solids to filter (lb/hr)}}{\text{surface area (sq ft)}} \tag{32.9}$$

### Example 32.10

*Problem*

Digested biosolids are applied to a vacuum filter at a rate of 70 gpm, with a solids concentration of 3%. If the vacuum filter has a surface area of 300 sq ft, what is the filter loading (in lb/hr/sq ft)?

*Solution*

$$\text{Filter loading (lb/hr/sq ft)} = \frac{\text{biosolids (gpm)} \times 60 \text{ min/hr} \times 8.34 \text{ lb/gal} \times (\text{\% solids/100})}{\text{surface area (sq ft)}}$$

$$= \frac{70 \text{ gpm} \times 60 \text{ min/hr} \times 8.34 \text{ lb/gal} \times (3/100)}{300 \text{ sq ft}}$$

$$= 3.5 \text{ lb/hr/sq ft}$$

### Filter Yield

One of the most common measures of vacuum filter performance is filter yield. It is the lb/hr of dry solids in the dewatered biosolids (cake) discharged per sq ft of filter area:

$$\text{Filter yield (lb/hr/sq ft)} = \frac{\text{wet cake flow (lb/hr)} \times (\text{\% solids in cake/100})}{\text{filter area (sq ft)}} \tag{32.10}$$

**Example 32.11**

*Problem*

The wet cake flow from a vacuum filter is 9000 lb/hr. If the filter areas is 300 sq ft and the percent solids in the cake is 25%, what is the filter yield (in lb/hr/sq ft)?

*Solution*

Referring to Equation 32.10,

$$\text{Filter area (sq ft)} = \frac{9000 \text{ lb/hr} \times \frac{25}{100}}{300 \text{ sq ft}}$$

$$= 7.5 \text{ lb/hr sq ft}$$

### Vacuum Filter Operating Time

The vacuum filter operating time required to process a given lb/d solids can be calculated using Equation 32.10; however, the vacuum filter operating time, of course, is the unknown factor ($x$).

**Example 32.12**

*Problem*

A vacuum filter must process 4000 lb/day primary biosolids solids. The vacuum filter yield is 2.2 lb/hr/sq ft. The solids recovery is 95%. If the area of the filter is 210 sq ft, how many hours per day must the vacuum filter remain in operation to process these solids?

*Solution*

Referring to Equation 32.10:

$$\text{Filter yield (lb/hr/sq ft)} = \frac{\frac{\text{solids to filter (lb/day)}}{\text{filter operation (lb/day)}}}{\text{filter area (sq ft)}} \times \frac{\text{\% recovery}}{100}$$

$$2.2\text{-lb/hr/sq ft} = \frac{\frac{4000 \text{ lb/day}}{x \text{ hr/day operation}}}{210 \text{ sq ft}} \times \frac{95}{100}$$

$$2.2\text{-lb/hr/sq ft} = \frac{4000 \text{ lb/day}}{x \text{ hr/day}} \times \frac{1}{210 \text{ ft}^2} \times \frac{95}{100}$$

$$x = \frac{4000 \times 1 \times 95}{2.2 \times 210 \times 100}$$

$$x = 8.2 \text{ hr/d}$$

### Percent Solids Recovery

As mentioned, the function of the vacuum filtration process is to separate the solids from the liquids in the biosolids being processed; therefore, the percent of feed solids recovered (sometimes referred

to as the percent solids capture) is a measure of the efficiency of the process. Equation 32.11 is used to determine percent solids recovery.

$$\%\text{ Solids recovered} = \frac{\text{wet cake flow (lb/hr)} \times \dfrac{\%\text{ solids in cake}}{100}}{\text{biosolids feed rate (lb/hr)} \times \dfrac{\%\text{ solids in feed}}{100}} \times 100 \qquad (32.11)$$

**Example 32.13**

*Problem*

The biosolids feed rate to a vacuum is 3400 lb/day, with a solids content of 5.1%. If the wet cake flow is 600 lb/hr with a 25% solids content, what is the percent solids recovery?

*Solution*

Referring to Equation 32.11:

$$\%\text{ Solids recovered} = \frac{600\text{ lb/hr} \times \dfrac{25}{100}}{3400\text{ lb/hr} \times \dfrac{5.1}{100}} \times 100$$

$$= \frac{150\text{ lb/hr}}{173\text{ lb/hr}} \times 100$$

$$= 87\%$$

## SAND DRYING BED CALCULATIONS

Drying beds are generally used for dewatering well-digested biosolids. Biosolids drying beds consist of a perforated or open joint drainage system in a support media, usually gravel or wire mesh. Drying beds are usually separated into workable sections by wood, concrete, or other materials. Drying beds may be enclosed or opened to the weather. They may rely entirely on natural drainage and evaporation processes or may use a vacuum to assist the operation. *Sand drying beds* are the oldest biosolids dewatering technique and consist of 6 to 12 inches of coarse sand underlain by layers of graded gravel ranging from 1/8 to 1/4 inches at the top and 3/4 to 1-1/2 inches on the bottom. The total gravel thickness is typically about 1 ft. Graded natural earth (4 to 6 in.) usually makes up the bottom, with a web of drain tile placed on 20- to 30-ft centers. Sidewalls and partitions between bed sections are usually made of wooden planks or concrete and extend about 14 inches above the sand surface.

### Sand Drying Beds Process Control Calculations

Typically, three calculations are used to monitor sand drying bed performance: total biosolids applied, solids loading rate, and biosolids withdrawal to drying beds.

#### Total Biosolids Applied

The total gallons of biosolids applied to sand drying beds may be calculated using the dimensions of the bed and depth of biosolids applied:

$$\text{Volume (gal)} = \text{Length (ft)} \times \text{width (ft)} \times \text{depth (ft)} \times 7.48\text{ gal/cu ft} \qquad (32.12)$$

**Example 32.14**

*Problem*

A drying bed is 220 ft long by 20 ft wide. If biosolids are applied to a depth of 4 inches, how many gallons of biosolids are applied to the drying bed?

*Solution*

Referring to Equation 32.12:

$$\text{Volume (gal)} = 220 \text{ ft} \times 20 \text{ ft} \times 0.33 \text{ ft} \times 7.48 \text{ gal/cu ft}$$

$$= 10{,}861 \text{ gal}$$

## Solids Loading Rate

The biosolids loading rate may be expressed as lb/yr/sq ft. The loading rate is dependent on biosolids applied per applications (lb), percent solids concentration, cycle length, and square feet of sand bed area:

$$\text{Solids loading rate (lb/yr/sq ft)} = \frac{\dfrac{\text{biosolids applied (lb)}}{\text{days of application}} \times 365 \text{ days/yr} \times \dfrac{\%\text{ solids}}{100}}{\text{length (ft)} \times \text{width (ft)}} \tag{32.13}$$

**Example 32.15**

*Problem*

A biosolids bed is 210 ft long by 25 ft wide. A total of 172,500 lb of biosolids is applied during each application of the sand drying bed. The biosolids has a solids content of 5%. If the drying and removal cycle requires 21 days, what is the solids loading rate (in lb/yr/sq ft)?

*Solution*

Referring to Equation 32.13:

$$\text{Solids loading rate (lb/yr/sq ft)} = \frac{\dfrac{172{,}500 \text{ lb}}{21 \text{ days}} \times 365 \text{ days/yr} \times \dfrac{5}{100}}{210 \text{ ft} \times 25 \text{ ft}}$$

$$= 37.5 \text{ lb/yr/sq ft}$$

## Biosolids Withdrawal to Drying Beds

Pumping digested biosolids to drying beds is one method among many for dewatering biosolids, thus making the dried biosolids useful as a soil conditioner. Depending upon the climate of a region, the drying bed depth may range from 8 to 18 inches; therefore, the area covered by these drying beds may be substantial. For this reason, the use of drying beds is more common for smaller plants than for larger plants. Use the following to calculate biosolids withdrawal to drying beds:

$$\text{Biosolids withdrawn (cu ft)} = 0.785 \times D^2 \times \text{drawdown (ft)} \tag{32.14}$$

**Example 32.16**

*Problem*

Biosolids are withdrawn from a digester that has a diameter of 40 feet. If the biosolids are drawn down 2 feet, how many cu ft will be sent to the drying beds?

*Solution*

Referring to Equation 32.14:

$$\text{Biosolids withdrawn (cu ft)} = 0.785 \times 40 \text{ ft} \times 40 \text{ ft} \times 2 \text{ ft}$$

$$= 2512 \text{ cu ft}$$

## BIOSOLIDS DISPOSAL

In the disposal of biosolids, land application, in one form or another, has become not only a necessity (because of the banning of ocean dumping in the U.S. in 1992 and the shortage of landfill space since then) but is also quite popular as a beneficial reuse practice. That is, beneficial reuse means that the biosolids are disposed of in an environmentally sound manner by recycling nutrients and soil conditions. Biosolids are being applied throughout the U.S. to agricultural and forest lands. For use in land applications, the biosolids must meet certain conditions. Biosolids must comply with state and federal biosolids management/disposal regulations and must also be free of materials posing a hazard to human health (e.g., toxins, pathogenic organisms) or are dangerous to the environment (e.g., toxins, pesticides, heavy metals). Biosolids are land applied by direct injection, by incorporation (plowing in), or by composting.

### LAND APPLICATION CALCULATIONS

Land application of biosolids requires precise control to avoid problems. Use of process control calculations is part of the overall process control process. Calculations include determining disposal cost, plant available nitrogen (PAN), application rate (dry tons and wet tons/acre), metals loading rates, maximum allowable applications based upon metals loading, and site life based on metals loading.

#### Disposal Cost

The cost of disposal of biosolids can be determined by:

$$\text{Cost} = \text{Biosolids produced (wet ton/yr)} \times \% \text{ solids} \times \text{cost/dry ton} \qquad (32.15)$$

#### Example 32.17

*Problem*

The treatment system produces 1925 wet tons of biosolids for disposal each year. The biosolids are 18% solids. A contractor disposes of the biosolids for \$28.00 per dry ton. What is the annual cost for biosolids disposal?

*Solution*

Referring to Equation 32.15:

$$\text{Cost} = 1925 \text{ wet tons/yr} \times 0.18 \times \$28.00\text{/dry ton} = \$9702$$

#### Plant Available Nitrogen (PAN)

One factor considered when land applying biosolids is the amount of nitrogen in the biosolids available to the plants grown on the site. This includes ammonia nitrogen and organic nitrogen. The organic nitrogen must be mineralized for plant consumption. Only a portion of the organic nitrogen is mineralized per year. The mineralization factor ($f^1$) is assumed to be 0.20. The amount of ammonia nitrogen available is directly related to the time elapsed between applying the biosolids

and incorporating (plowing) the biosolids into the soil. We provide volatilization rates based upon the example below.

$$\text{PAN (lb/dry ton)} = \left\{\left[\text{organic nitrogen (mg/kg)} \times f^1\right] + \left[\text{ammonium nitrate (mg/kg)} \times V_1\right]\right\} \times 0.002 \text{ lb/dry ton}$$

where

$f^1$ = Mineral rate for organic nitrogen (assume 0.20)
$V_1$ = Volatilization rate ammonia nitrogen
$V_1$ = 1.00 if biosolids are injected
$V_1$ = 0.85 if biosolids are plowed in within 24 hours
$V_1$ = 0.70 if biosolids are plowed in within 7 days

### Example 32.18

*Problem*

Biosolids contain 21,000 mg/kg organic nitrogen and 10,500 mg/kg ammonia nitrogen. The biosolids are incorporated into the soil within 24 hours after application. What is the plant available nitrogen per dry ton of solids?

*Solution*

Referring to Equation 32.16:

$$\text{PAN (lb/dry ton)} = [(21{,}000 \text{ mg/kg} \times 0.20) + (10{,}500 \times 0.85)] \times 0.002$$

$$= 26.3 \text{ lb/dry ton}$$

### Application Rate Based on Crop Nitrogen Requirement

In most cases, the application rate of domestic biosolids to crop lands will be controlled by the amount of nitrogen the crop requires. The biosolids application rate based on the nitrogen requirement is determined by the following:

- Using an agriculture handbook to determine the nitrogen requirement of the crop to be grown
- Determining the amount of biosolids in dry tons required to provide this much nitrogen:

$$\text{Dry tons/acre} = \frac{\text{plant nitrogen requirement (lb/acre)}}{\text{plant available nitrogen (lb/dry ton)}} \tag{32.17}$$

### Example 32.19

*Problem*

The crop to be planted on the land application site requires 150 lb of nitrogen per acre. What is the required biosolids application rate if the PAN of the biosolids is 30 lb/dry ton?

*Solution*

Referring to Equation 32.17:

$$\text{Dry tons/acre} = \frac{150 \text{ lb nitrogen/acre}}{30 \text{ lb/dry ton}} = 5 \text{ dry tons/acre}$$

### Metals Loading

When biosolids are land applied, metals concentrations are closely monitored and their loading on land application sites are calculated:

$$\text{Loading rate (lb/acre)} = \text{Metal concentration (mg/kg)} \times 0.002 \text{ lb/dry ton} \times \text{application rate (dry ton/acre)} \tag{32.18}$$

### Example 32.20

*Problem*

Biosolids contain 14 mg/kg lead. Biosolids are currently being applied to the site at a rate of 11 dry tons per acre. What is the metals loading rate for lead (in pounds per acre)?

*Solution*

Referring to Equation 32.18:

$$\text{Loading rate (lb/acre)} = 14 \text{ mg/kg} \times 0.002 \text{ lb/dry ton} \times 11 \text{ dry tons} = 0.31 \text{ lb/acre}$$

### Maximum Allowable Applications Based on Metals Loading

If metals are present, they may limit the total number of applications a site can receive. Metals loadings are normally expressed in terms of the maximum total amount of metal that can be applied to a site during its use:

$$\text{Applications} = \frac{\text{maximum allowable cumulative load for the metal (lb/ac)}}{\text{Metal loading (lb/ac/application)}} \tag{32.19}$$

### Example 32.21

*Problem*

The maximum allowable cumulative lead loading is 48.0 lb/acre. Based upon the current loading of 0.35 lb/acre, how many applications of biosolids can be made to this site?

*Solution*

Referring to Equation 32.19:

$$\text{Applications} = \frac{48.0 \text{ lb/acre}}{0.35 \text{ lb/acre}} = 137$$

### Site Life Based on Metals Loading

The maximum number of applications based on metals loading and the number of applications per year can be used to determine the maximum site life:

$$\text{Site life (years)} = \frac{\text{maximum allowable applications}}{\text{number of applications planned / year}} \tag{32.20}$$

**Example 32.21**

*Problem*

Biosolids are currently applied to a site twice annually. Based upon the lead content of the biosolids, the maximum number of applications is determined to be 135 applications. Based upon the lead loading and the applications rate, how many years can this site be used?

*Solution*

Referring to Equation 32.20:

$$\text{Site life} = \frac{135 \text{ applications}}{2 \text{ applications/year}} = 68 \text{ years} \tag{32.21}$$

✍ **Key Point:** When more than one metal is present, the calculations must be performed for each metal. The site life would then be the lowest value generated by these calculations.

## BIOSOLIDS TO COMPOST

The purpose of composting biosolids is to stabilize the organic matter, reduce volume, eliminate pathogenic organisms, and produce a product that can be used as a soil amendment or conditioner. Composting is a biological process. In a composting operation, dewatered solids are usually mixed with a bulking agent (e.g., hardwood chips) and stored until biological stabilization occurs (see Figure 32.5). The composting mixture is ventilated during storage to provide sufficient oxygen for oxidation and to prevent odors. After the solids are stabilized, they are separated from the bulking agent. The composted solids are then stored for curing and are applied to farm lands or other beneficial uses. Expected performance of the composting operation for both percent volatile matter reduction and percent moisture reduction ranges from 40 to 60%.

Performance factors related to biosolids composting include moisture content, temperature, pH, nutrient availability, and aeration. The biosolids must contain sufficient moisture to support the biological activity. If the moisture level is too low (40% or less), biological activity will be reduced or stopped. At the same time, if the moisture level exceeds approximately 60%, it will prevent sufficient airflow through the mixture.

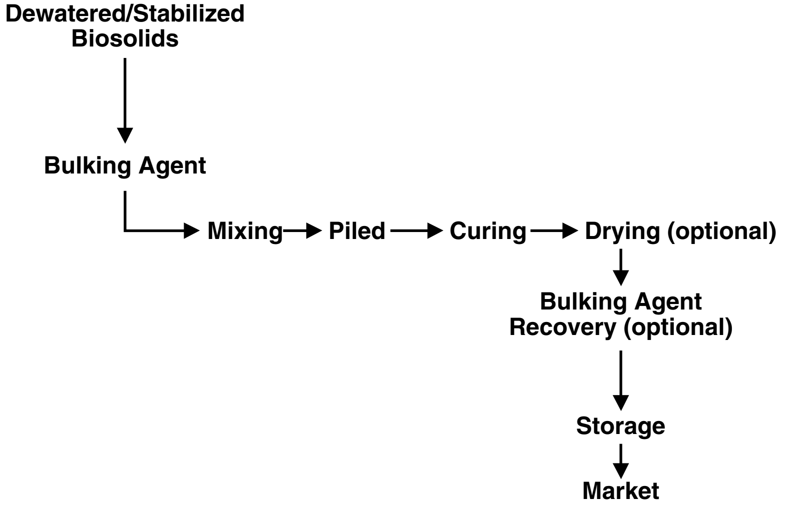


**FIGURE 32.5** Flow diagram for composting biosolids.

The composting process operates best when the temperature is maintained within an operating range of 130 to 140°F. Biological activities provide enough heat to increase the temperature well above this range, so forced air ventilation or mixing is required to remove heat and maintain the desired operating temperature range. The temperature of the composting solids, when maintained at the required levels, will be sufficient to remove pathogenic organisms.

The influent pH can affect the performance of the process if extreme (less than 6.0 or greater than 11.0). The pH during composting may have some impact on the biological activity but does not appear to be a major factor. Composted biosolids generally have a pH in the range of 6.8 to 7.5.

The critical nutrient in the composting process is nitrogen. The process works best when the ratio of nitrogen to carbon is in the range of 26 to 30 carbon to 1 nitrogen. Above this ratio, composting is slowed; below this ratio, the nitrogen content of the final product may be less attractive as compost.

Aeration is essential to provide oxygen to the process and to control the temperature. In forced air processes, some means of odor control should be included in the design of the aeration system.

## Composting Calculations

Pertinent composting process control calculations include determination of percent of moisture of compost mixture and compost site capacity.

### Blending Dewatered Biosolids with Composted Biosolids

Blending composted material with dewatered biosolids is similar to blending two different percent solids biosolids. The percent solids (or percent moisture) content of the mixture will always fall somewhere between the percent solids (or percent moisture) concentrations of the two materials being mixed. Equation (32.22) is used to determine percent moisture of mixture:

$$\text{\% Moisture of mixture} = \frac{\text{biosolids (lb/day)} \times \dfrac{\text{\% moisture}}{100} + \text{compost (lb/day)} \times \dfrac{\text{\% moisture}}{100}}{\text{biosolids (lb/day)} + \text{compost (lb/day)}} \times 100 \tag{32.22}$$

### Example 32.22

*Problem*

If 5000 lb/day dewatered biosolids are mixed with 2000 lb/day compost, what is the percent moisture of the blend? The dewatered biosolids have a solids content of 25% (75% moisture) and the compost has a 30% moisture content.

*Solution*

Referring to Equation 32.22:

$$\text{\% Moisture of mixture} = \frac{\left(5000\text{ lb/day} \times \dfrac{75}{100}\right) + \left(2000\text{ lb/day} \times \dfrac{30}{100}\right)}{5000\text{ lb/day} + 2000\text{ lb/day}} \times 100$$

$$= \frac{3750\text{ lb/day} + 600\text{ lb/day}}{7000\text{ lb/day}}$$

$$= 62\%$$

## Compost Site Capacity Calculation

An important consideration in compost operation is the solids processing capability (fill time) in lb/day or lb/week:

$$\text{Fill time (day)} = \frac{\text{total available capacity (cu yd)}}{\dfrac{\text{wet compost (lb/day)}}{\text{compost bulk density (lb/cu yd)}}} \tag{32.23}$$

### Example 32.23

*Problem*

A composting facility has an available capacity of 7600 cu yd. If the composting cycle is 21 days, how many pounds wet compost can be processed per day by this facility? Assume a compost bulk density of 900 lb/cu yd.

*Solution*

Referring to Equation 32.23:

$$21 \text{ days} = \frac{7600 \text{ cu yd}}{\dfrac{x \text{ lb/day}}{900 \text{ lb/cu yd}}}$$

$$21 \text{ days} = \frac{7600 \text{ yd}^3 \times 90 \text{ lb/cu yd}}{x \text{ lb/day}}$$

$$x \text{ lb/d} = \frac{7600 \text{ yd}^3 \times 900 \text{ lb/yd}^3}{21 \text{ days}}$$

$$x = 325{,}714 \text{ lb/day}$$

# Part IV

## Laboratory Calculations

# 33 Water/Wastewater Laboratory Calculations

## TOPICS



## WATER/WASTEWATER LAB

Ideally, waterworks and wastewater treatment plants are sized to meet both current and future needs. No matter the size of the treatment plant, some space or area within the plant is designated as the "lab" area (ranging from being closet sized to fully equipped and staffed environmental laboratories). Water/wastewater laboratories usually perform a number of different tests. Lab test results provide operators with the information necessary to operate the treatment facility at optimal levels. Laboratory testing usually involves service line flushing time, solution concentration, pH, chemical oxygen demand (COD), total phosphorus, fecal coliform count, chlorine residual, and biochemical oxygen demand (BOD) seeded tests, to name a few. The standard reference for performing wastewater testing is contained in *Standard Methods for the Examination of Water and Wastewater,* APHA, AWWA WEF, 1995.

In this chapter, we focus on standard water/wastewater lab tests that involve various calculations. Specifically, we focus on calculations used to determine a proportioning factor for composite sampling, flow from a faucet estimation, service line flushing time, solution concentration, BOD, molarity and moles, normality, settleability, settleable solids, biosolids total, fixed and volatile solids, suspended solids and volatile suspended solids, and biosolids volume and biosolids density indexes.

(*Note:* Water/wastewater labs usually determine chlorine residual and perform other standard solution calculations. These topics were covered in Chapter 28.

## FAUCET FLOW ESTIMATION

On occasion, the waterworks sampler must take water samples from a customer's residence. In small water systems, the sample is usually taken from the customer's front yard faucet. A convenient

flow rate for taking water samples is about 0.5 gpm. To estimate the flow from a faucet, use a 1-gallon container and record the time it takes to fill the container. To calculate the flow in gpm, insert the recorded information into Equation 33.1:

$$\text{Flow (gpm)} = \frac{\text{volume (gal)}}{\text{time (min)}} \tag{33.1}$$

**Example 33.1**

*Problem*

The flow from a faucet fills up the gallon container in 48 seconds. What is the gpm flow rate from the faucet? Because the flow rate is desired in minutes, the time should also be expressed as minutes:

$$\frac{\text{48 seconds}}{\text{60 sec/min}} = \text{0.80 minute}$$

*Solution*

Calculate flow rate from the faucet using Equation 33.1:

$$\begin{aligned}\text{Flow (gpm)} &= \frac{\text{1 gal}}{\text{0.80 min}}\\ &= \text{1.25 gpm}\end{aligned}$$

**Example 33.2**

*Problem*

The flow from a faucet fills up a gallon container in 55 seconds. What is the gpm flow rate from the faucet?

*Solution*

$$\frac{\text{55 seconds}}{\text{60 sec/min}} = \text{0.92 minute}$$

Calculate the flow rate using Equation 33.1:

$$\begin{aligned}\text{Flow rate (gpm)} &= \frac{\text{1 gal}}{\text{0.92 min}}\\ &= \text{1.1 gpm}\end{aligned}$$

## SERVICE LINE FLUSHING TIME

To determine the quality of potable water delivered to a consumer, a sample is taken from the customer's outside faucet — water that is typical of the water delivered. To obtain an accurate indication of the system water quality, this sample must be representative. Further, to ensure that the sample taken is typical of water delivered, the service line must be flushed twice. Equation 33.2 is used to calculate flushing time:

$$\text{Flushing time (min)} = \frac{0.785 \times D^2 \times \text{length (ft)} \times 7.48 \text{ gal/cu ft} \times 2}{\text{flow rate (gpm)}} \tag{33.2}$$

### Example 33.3

*Problem*

How long (minutes) will it take to flush a 40-ft length of 1/2-inch-diameter service line if the flow through the line is 0.5 gpm?

*Solution*

Calculate the diameter of the pump in feet:

$$\frac{0.50}{12 \text{ inches/ft}} = 0.04 \text{ ft}$$

Calculate the flushing time using Equation 33.2:

$$\text{Flushing time (min)} = \frac{0.785 \times 0.04 \text{ ft} \times 0.04 \text{ ft} \times 40 \text{ ft} \times 7.48 \text{ gal/cu ft} \times 2}{0.5 \text{ gpm}}$$

$$= 1.5 \text{ min}$$

### Example 33.4

*Problem*

At a flow rate of 0.5 gpm, how long (minutes and seconds) will it take to flush a 60-ft length of 3/4-inch service line?

*Solution*

$$\text{3/4-inch diameter} = 0.06 \text{ ft}$$

Use Equation 33.2 to determine flushing time:

$$\text{Flushing time (min)} = \frac{0.785 \times 0.06 \text{ ft} \times 0.06 \text{ ft} \times 60 \text{ ft} \times 7.48 \text{ gal/cu ft} \times 2}{0.5 \text{ gpm}}$$

$$= 5.1 \text{ min}$$

Convert the fractional part of a minute (0.1) to seconds:

$$0.1 \text{ min} \times 60 \text{ sec/min} = 6 \text{ seconds}$$

Thus, the flushing time is 5.01 min, or 5 minutes 6 seconds.

## COMPOSITE SAMPLING CALCULATION (PROPORTIONING FACTOR)

When preparing oven-baked food, a cook is careful to set the correct oven temperature and then usually moves on to some other chore while the oven thermostat makes sure that the oven-baked

food is cooked at the correct temperature. Unlike this cook, in water/wastewater treatment plant operations the operator does not have the luxury of setting a plant parameter and then walking off and forgetting about it. To optimize plant operations, various adjustments to unit processes must be made on an ongoing basis. The operator makes unit process adjustments based on local knowledge (experience) and on lab test results; however, before lab tests can be performed, samples must be taken.

The two basic types of samples are *grab samples* and *composite samples*. The type of sample taken depends on the specific test, the reason the sample is being collected, and the requirements in the plant discharge permit. A grab sample is a discrete sample collected at one time and in one location. Such samples are primarily used for any parameter for which the concentration can change quickly (e.g., dissolved oxygen, pH, temperature, total chlorine residual), and they are representative only of the conditions at the time of collection. A composite sample consists of a series of individual grab samples taken at specified time intervals and in proportion to flow. The individual grab samples are mixed together in proportion to the flow rate at the time the sample was collected to form a composite sample. The composite sample represents the character of the water/wastewater over a period of time.

## Composite Sampling Procedure and Calculation

Because knowledge of the procedure used in processing composite samples is important (a basic requirement) to the water/wastewater operator, the actual procedure used is covered in this section.

### Procedure

- Determine the total amount of sample required for all tests to be performed on the composite sample.
- Determine the average daily flow of the treatment system.

✓ **Key Point:** Average daily flow can be determined by using several months of data which will provide a more representative value.

- Calculate a proportioning factor:

$$\text{Proportioning factor (PF)} = \frac{\text{total sample volume required (mm)}}{\text{No. of samples to be calculated} \times \text{average daily flow (MGD)}} \tag{33.3}$$

✓ **Key Point:** Round the proportioning factor to the nearest 50 units (50, 100, 150, etc.) to simplify calculation of the sample volume.

- Collect the individual samples in accordance with the schedule (e.g., once/hour, once/15 minutes).
- Determine flow rate at the time the sample was collected.
- Calculate the specific amount to add to the composite container:

$$\text{Required volume (mL)} = \text{Flow}^{T} \times \text{PF} \tag{33.4}$$

  where $T$ = time sample was collected.
- Mix the individual sample thoroughly; measure the required volume and add it to the composite storage container.
- Refrigerate the composite sample throughout the collection period.

**Example 33.5**

*Problem*

Effluent testing will require 3825 milliliters of sample. The average daily flow is 4.25 million gallons per day. Using the flows given below, calculate the amount of sample to be added at each of the times shown:

| Time | Flow (MGD) |
|---|---|
| 8 a.m. | 3.88 |
| 9 a.m. | 4.10 |
| 10 a.m. | 5.05 |
| 11 a.m. | 5.25 |
| 12 noon | 3.80 |
| 1 p.m. | 3.65 |
| 2 p.m. | 3.20 |
| 3 p.m. | 3.45 |
| 4 p.m. | 4.10 |

*Solution*

$$\text{Proportioning factor (PF)} = \frac{3825 \text{ mL}}{9 \text{ samples} \times 4.25 \text{ MGD}}$$

$$= 100$$

$\text{Volume}_{8\text{a.m.}} = 3.88 \times 100 = 388\ (400)$ mL
$\text{Volume}_{9\text{a.m.}} = 4.10 \times 100 = 410\ (410)$ mL
$\text{Volume}_{10\text{a.m.}} = 5.05 \times 100 = 505\ (500)$ mL
$\text{Volume}_{11\text{a.m.}} = 5.25 \times 100 = 525\ (530)$ mL
$\text{Volume}_{12\text{ noon}} = 3.80 \times 100 = 380\ (380)$ mL
$\text{Volume}_{1\text{p.m.}} = 3.65 \times 100 = 365\ (370)$ mL
$\text{Volume}_{2\text{p.m.}} = 3.20 \times 100 = 320\ (320)$ mL
$\text{Volume}_{3\text{p.m.}} = 3.45 \times 100 = 345\ (350)$ mL
$\text{Volume}_{4\text{p.m.}} = 4.10 \times 100 = 410\ (410)$ mL

## BIOCHEMICAL OXYGEN DEMAND (BOD) CALCULATIONS

*Biochemical oxygen demand* (BOD) measures the amount of organic matter that can be biologically oxidized under controlled conditions (5 days at 20°C in the dark). Several criteria are considered when selecting which BOD dilutions to use for calculating test results. Consult a laboratory testing reference manual (such as *Standard Methods*) for this information. Of the two basic calculations for BOD, the first is used for samples that have not been seeded, while the second must be used whenever BOD samples are seeded. We introduce both methods and provide examples below:

- BOD (unseeded)

$$\text{BOD (unseeded)} = \frac{\left[\text{DO}_{\text{start}}\ (\text{mg/L}) - \text{DO}_{\text{final}}\ (\text{mg/L})\right] \times 300 \text{ mL}}{\text{sample volume (mL)}} \qquad (33.5)$$

### Example 33.6

*Problem*

A BOD test has been completed. Bottle 1 of the test had dissolved oxygen (DO) of 7.1 mg/L at the start of the test. After 5 days, bottle 1 had a DO of 2.9 mg/L. Bottle 1 contained 120 mg/L of sample.

*Solution*

$$\text{BOD (unseeded)} = \frac{(7.1 \text{ mg/L} - 2.9 \text{ mg/L}) \times 300 \text{ mL}}{120 \text{ mL}} = 10.5 \text{ mg/L}$$

- BOD (seeded) — If the BOD sample has been exposed to conditions that could reduce the number of healthy, active organisms, the sample must be seeded with organisms. Seeding requires the use of a correction factor to remove the BOD contribution of the seed material:

$$\text{Seed correction} = \frac{\text{seed material BOD} \times \text{seed in dilution (mL)}}{300 \text{ mL}} \tag{33.6}$$

$$\text{BOD (seeded)} = \frac{[\text{DO}_{\text{start}} \text{ (mg/L)} - \text{DO}_{\text{final}} \text{ (mg/L)} - \text{seed correction}] \times 300}{\text{sample volume (mL)}} \tag{33.7}$$

### Example 33.7

*Problem*

Using the data provided below, determine the BOD:

| **Dilution 1** | |
|---|---|
| BOD of seed material | 90 mg/L |
| Seed material | 3 mL |
| Sample | 100 mL |
| Start dissolved oxygen | 7.6 mg/L |
| Final dissolved oxygen | 2.7 mg/L |

*Solution*

Referring to Equation 33.6:

$$\text{Seed correction} = \frac{90 \text{ mg/L} \times 3 \text{ mL}}{300 \text{ mL}} = 0.90 \text{ mg/L}$$

Referring to Equation 33.7:

$$\text{BOD (seeded)} = \frac{(7.6 \text{ mg/L} - 2.7 \text{ mg/L} - 0.90) \times 300}{100 \text{ mL}} = 12 \text{ mg/L}$$

## BOD 7-Day Moving Average

Because the BOD characteristic of wastewater varies from day to day, even hour-to-hour, operational control of the treatment system is most often accomplished based on trends in data rather than individual data points. The BOD 7-day moving average is a calculation of the BOD trend.

✔ **Key Point:** The 7-day moving average is called a moving average because a new average is calculated each day by adding the new day's value and the six previous days' values:

$$\text{7-Day average BOD} = \frac{\text{BOD}_{\text{Day 1}} + \text{BOD}_{\text{Day 2}} + \text{BOD}_{\text{Day 3}} + \text{BOD}_{\text{Day 4}} + \text{BOD}_{\text{Day 5}} + \text{BOD}_{\text{Day 6}} + \text{BOD}_{\text{Day 7}}}{7} \tag{33.8}$$

### Example 33.8

*Problem*

Given the following primary effluent BOD test results, calculate the 7-day average.

| | |
|---|---|
| June 1 — 200 mg/L | June 5 — 222 mg/L |
| June 2 — 210 mg/L | June 6 — 214 mg/L |
| June 3 — 204 mg/L | June 7 — 218 mg/L |
| June 4 — 205 mg/L | |

$$\text{7-Day average BOD} = \frac{200 + 210 + 204 + 205 + 222 + 214 + 218}{7}$$

$$= 210 \text{ mg/L}$$

# MOLES AND MOLARITY

Chemists have defined a very useful unit called the *mole.* Moles and *molarity*, a concentration term based on the mole, have many important applications in water/wastewater operations. A mole is defined as a gram molecular weight; that is, the molecular weight expressed as grams. For example, a mole of water is 18 grams of water, and a mole of glucose is 180 grams of glucose. A mole of any compound always contains the same number of molecules. The number of molecules in a mole is called *Avogadro's number* and has a value of $6.022 \times 10^{23}$.

✔ **Interesting Point:** How big is Avogadro's number? An Avogadro's number of soft drink cans would cover the surface of the Earth to a depth of over 200 miles.

✔ **Key Point:** Molecular weight is the weight of one molecule. It is calculated by adding the weights of all the atoms that are present in one molecule. The units are atomic mass units (amu). A mole is a gram molecular weight — that is, the molecular weight expressed in grams. The molecular weight is the weight of one molecule in daltons (Da). All moles contain the same number of molecules — Avogadro's number, which is equal to $6.022 \times 10^{23}$. The reason all moles have the same number of molecules is because the value of the mole is proportional to the molecular weight.

## Moles

As mentioned, a mole is a quantity of a compound equal in weight to its formula weight. For example, the formula weight for water ($H_2O$; see Figure 33.1) can be determined using the Periodic Table of Elements:

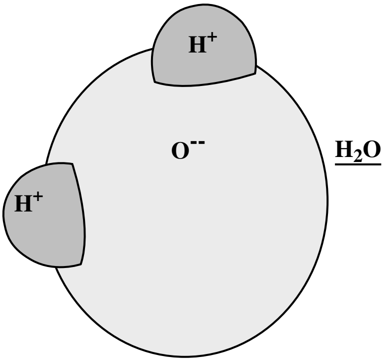


**FIGURE 33.1** A molecule of water.

$$\text{Hydrogen } (1.008) \times 2 = 2.016$$

$$\text{Oxygen} = \underline{16.000}$$

$$\text{Formula weight of } H_2O = 18.016$$

Because the formula weight of water is 18.016, a mole is 18.016 units of weight. A *gram-mole* is 18.016 grams of water. A *pound-mole* is 18.016 pounds of water. For our purposes in this text, the term *mole* will be understood to represent a gram-mole. The equation used to determine moles is shown below.

$$\text{Moles} = \frac{\text{grams of chemical}}{\text{formula weight of chemical}} \tag{33.9}$$

### Example 33.9

*Problem*

The atomic weight of a certain chemical is 66. If 35 grams of the chemical are used to make up a 1-liter solution, how many moles are used?

*Solution*

Referring to Equation 33.9:

$$\text{Moles} = \frac{66 \text{ grams}}{35 \text{ grams/mole}}$$

$$= 1.9 \text{ moles}$$

The molarity of a solution is calculated by taking the moles of solute and dividing by the liters of solution. The molarity of a solution is calculated by taking the moles of solute and dividing by the liters of solution:

$$\text{Molarity} = \frac{\text{moles of solute}}{\text{liters of solution}} \tag{33.10}$$

### Example 33.10

*Problem*

What is the molarity of 2 moles of solute dissolved in 1 liter of solvent?

*Solution*

Referring to Equation 33.10:

$$\text{Molarity} = \frac{2 \text{ moles}}{1 \text{ liter}} = 2\ M$$

✔ **Key Point:** Measurement in moles is a measurement of the amount of a substance. Measurement in molarity is a measurement of the concentration of a substance — the amount (moles) per unit volume (liters).

## NORMALITY

As mentioned, the *molarity* of a solution refers to its concentration (the solute dissolved in the solution). The *normality* of a solution refers to the number of *equivalents* of solute per liter of solution. The definition of chemical equivalent depends on the substance or type of chemical reaction under consideration. Because the concept of equivalents is based on the reacting power of an element or compound, it follows that a specific number of equivalents of one substance will react with the same number of equivalents of another substance. When the concept of equivalents is taken into consideration, it is less likely that chemicals will be wasted as excess amounts.

Keeping in mind that normality is a measure of the reacting power of a solution (i.e., 1 equivalent of a substance reacts with 1 equivalent of another substance), we use the following equation to determine normality.

$$\text{Normality} = \frac{\text{number of equivalents of solute}}{\text{liters of solution}} \tag{33.11}$$

### Example 33.11

*Problem*

If 2.0 equivalents of a chemical are dissolved in 1.5 liters of solution, what is the normality of the solution?

*Solution*

Referring to Equation 33.11:

$$\text{Normality} = \frac{2.0 \text{ equivalents}}{1.5 \text{ liters}}$$

$$= 1.33\ N$$

### Example 33.12

*Problem*

An 800-mL solution contains 1.6 equivalents of a chemical. What is the normality of the solution?

*Solution*

First convert 800 mL to liters:

$$\frac{800 \text{ mL}}{1000 \text{ mL}} = 0.8 \text{ L}$$

Then, calculate the normality of the solution using Equation 33.11:

$$\text{Normality} = \frac{1.6\ \text{equivalents}}{0.8\ \text{liters}}$$

$$= 2\ N$$

## SETTLEABILITY (ACTIVATED BIOSOLIDS SOLIDS)

The settleability test is a test of the quality of the activated biosolids solids — or activated sludge solids (mixed liquor suspended solids, MLSS). Settled biosolids volume (SBV), or settled sludge volume (SSV), is determined at specified times during sample testing. Thirty- and 60-minute observations are used for control. Subscripts (e.g., $SBV_{30}$, $SSV_{30}$, $SBV_{60}$, $SSV_{60}$) indicate settling time. A sample of activated biosolids is taken from the aeration tank, poured into a 2000-mL graduated cylinder, and allowed to settle for 30 or 60 minutes. The settling characteristics of the biosolids in the graduate give a general indication of the settling of the MLSS in the final clarifier. From the settleability test, the percent settleable solids can be calculated using the following equation:

$$\%\ \text{Settleable solids} = \frac{\text{settled solids (mL)}}{2000\text{-mL sample}} \times 100 \tag{33.12}$$

### Example 33.13

*Problem*

The settleability test is conducted on a sample of MLSS. What is the percent settleable solids if 420 milliliters settle in the 2000-mL graduated cylinder?

*Solution*

Referring to Equation 33.12:

$$\%\ \text{Settleable solids} = \frac{420\ \text{mL}}{2000\ \text{mL}} \times 100$$

$$= 21\%$$

### Example 33.14

*Problem*

A 2000-mL sample of activated biosolids is tested for settleability. If the settled solids are measured as 410 milliliters, what is the percent settled solids?

*Solution*

Again referring to Equation 33.12:

$$\%\ \text{Settleable solids} = \frac{410\ \text{mL}}{2000\ \text{mL}} \times 100$$

$$= 20.5\%$$

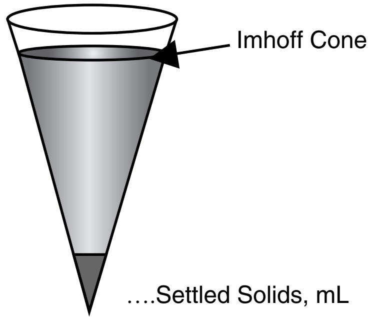


**FIGURE 33.2** 1-Liter Imhoff cone.

## SETTLEABLE SOLIDS

The settleable solids test is an easy, quantitative method to measure sediment found in wastewater. An Imhoff cone (a plastic or glass 1-liter cone; see Figure 33.2) is filled with 1 liter of sample wastewater, stirred, and allowed to settle for 60 minutes. The settleable solids test, unlike the settleability test, is conducted on samples from sedimentation tank or clarifier influent and effluent to determine the percent removal of settleable solids. The percent settleable solids is determined by:

$$\%\text{ Settleable solids removed} = \frac{\text{settled solids removed }(\text{mL/L})}{\text{settled solids in influent }(\text{mL/L})} \times 100 \qquad (33.13)$$

### Example 33.15

*Problem*

Calculate the percent removal of settleable solids if the settleable solids of the sedimentation tank influent is 15 mL/L and the settleable solids of the effluent is 0.4 mL/L.

*Solution*

First:

$$\text{Removed settleable solids (mL/L)} = 15.0 - 0.4\text{ mL/L} = 14.6\text{ mL/L}$$

Next, insert parameters into Equation 33.13:

$$\%\text{ settleable solids removed} = \frac{14.6\text{ mL/L}}{15.0\text{ mL/L}} \times 100$$

$$= 97\%$$

### Example 33.16

*Problem*

Calculate the percent removal of settleable solids if the settleable solids of the sedimentation tank influent is 13 mL/L and the settleable solids of the effluent is 0.5 mL/L.

*Solution*

First:

$$\%\text{ Settleable solids removed} = 13.0 - 0.5\text{ mL/L} = 12.5\text{ mL/L}$$

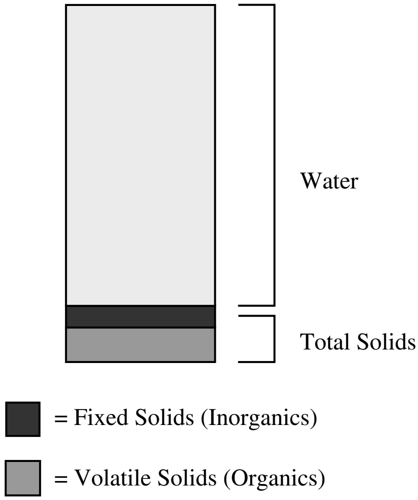


**FIGURE 33.3** Composition of wastewater.

Then, using Equation 33.13:

$$\% \text{ Settled solids removed} = \frac{12.5 \text{ mL/L}}{13.0 \text{ mL/L}} \times 100$$

$$= 96\%$$

## BIOSOLIDS TOTAL SOLIDS, FIXED SOLIDS, AND VOLATILE SOLIDS

Wastewater consists of both water and solids (see Figure 33.3). The *total solids* may be further classified as either *volatile solids* (organics) or *fixed solids* (inorganics). Normally, total solids and volatile solids are expressed as percents, whereas suspended solids are generally expressed as mg/L. To calculate either percents or milligram per liter concentrations, certain concepts must be understood:

- *Total solids* — The residue left in the vessel after evaporation of liquid from a sample and subsequent drying in an oven at 103 to 105˚C.
- *Fixed solids* — The residue left in the vessel after a sample is ignited (heated to dryness at 550˚C).
- *Volatile solids* — The weight loss after a sample is ignited (heated to dryness at 550˚C).

Determinations of fixed and volatile solids do not distinguish precisely between inorganic and organic matter because the loss on ignition is not confined to organic matter. It includes losses due to decomposition or volatilization of some mineral salts.

✓ **Key Point:** When the term *biosolids* is used, it may be understood to mean a semi-liquid mass composed of solids and water. The term *solids*, however, is used to mean dry solids after the evaporation of water.

Percent total solids and volatile solids are calculated as follows:

$$\% \text{ Total solids} = \frac{\text{total solids weight}}{\text{biosolids sample weight}} \times 100 \tag{33.14}$$

$$\% \text{ Volatile solids} = \frac{\text{volatile solids weight}}{\text{total solids weight}} \times 100 \tag{33.15}$$

**Example 33.17**

*Problem*

Given the information below, determine the percent solids in the sample and the percent volatile solids in the biosolids sample:

| | Biosolids Sample (g) | After Drying (g) | After Burning (Ash) (g) |
|---|---|---|---|
| Weight of sample and dish | 73.43 | 24.88 | 22.98 |
| Weight of dish (tare weight) | 22.28 | 22.28 | 22.28 |

To calculate the percent total solids, the grams total solids (solids after drying) and grams biosolids sample must be determined:

| Total Solids (g) | | Biosolids Sample (g) | |
|---|---|---|---|
| Total solids and dish | 24.88 | Biosolids and dish | 73.43 |
| Weight of dish | –22.28 | Dish | –22.28 |
| Total solids | 2.60 | Biosolids | 51.15 |

$$\% \text{ Total solids} = \frac{\text{wt. of total solids}}{\text{wt. of biosolids sample}} \times 100$$

$$= \frac{2.60 \text{ grams}}{51.15 \text{ g}} \times 100$$

$$= 5\%$$

To calculate the percent volatile solids, the grams total solids and grams volatile solids must be determined. Because total solids has already been calculated, only the volatile solids must be calculated:

| | |
|---|---|
| Sample and dish *before* burning | 24.88 g |
| Sample and dish *after* burning | –22.98 g |
| Solids lost in burning | 1.90 g |

Referring to Equation 33.15:

$$\% \text{ Volatile solids} = \frac{1.90 \text{ g}}{2.60 \text{ g}} \times 100$$

$$= 73\%$$

## WASTEWATER SUSPENDED SOLIDS AND VOLATILE SUSPENDED SOLIDS

*Total suspended solids* (TSS) are the amount of filterable solids in a wastewater sample. Samples are filtered through a glass fiber filter. The filters are dried and weighed to determine the amount of total suspended solids in mg/L of sample. *Volatile suspended solids* (VSS) are those solids lost on ignition (heating to 500°C.). They are useful to the treatment plant operator because they give a rough approximation of the amount of organic matter present in the solid fraction of wastewater, activated biosolids and industrial wastes. With the exception of the required drying time, the suspended solids and volatile suspended solids tests of wastewater are similar to those of the total and volatile solids performed for biosolids (described earlier). Calculation of suspended solids and volatile suspended solids is demonstrated in the Example 33.18.

✓ **Key Point:** The total and volatile solids of biosolids are generally expressed as percents, by weight. The biosolids samples are 100 mL and are unfiltered.

### Example 33.18

*Problem*

Given the following information regarding a primary effluent sample, calculate the mg/L suspended solids and the percent volatile suspended solids of the sample.

| | After Drying (Before Burning) (g) | After Burning (Ash) (g) |
|---|---|---|
| Weight of sample and dish | 24.6268 | 24.6232 |
| Weight of dish (tare weight) | 24.6222 | 24.6222 |
| Sample volume | 50 mL | |

*Solution*

To calculate the milligrams suspended solids per liter of sample (mg/L), we must first determine grams suspended solids:

| | |
|---|---|
| Dish and suspended solids | 24.6268 g |
| Dish | –24.6222 g |
| Suspended solids | 00.0046 g |

Next, we calculate mg/L suspended solids, using a multiplication factor of 20 (this number will vary with sample volume) to make the denominator equal to 1 liter (1000 mL):

$$\frac{0.0046 \text{ g SS}}{50 \text{ mL}} \times \frac{1000 \text{ mg}}{1 \text{ g}} \times \frac{20}{20} = \frac{92 \text{ mg}}{1000 \text{ mL}} = 92 \text{ mg/L SS}$$

To calculate percent volatile suspended solids, we must know the weight of both total suspended solids (calculated earlier) and volatile suspended solids:

| | |
|---|---|
| Dish and suspended solids *before* burning | 24.6268 g |
| Dish and suspended solids *after* burning | –24.6234 g |
| Solids lost in burning | 0.0034 g |

$$\% \text{ Volatile suspended solids} = \frac{\text{wt. of volatile solids}}{\text{wt. of suspended solids}} \times 100$$

$$= \frac{0.0034 \text{ g VSS}}{0.0046 \text{ g}} \times 100$$

$$= 74\% \text{ VSS}$$

## BIOSOLIDS VOLUME INDEX (BVI) AND BIOSOLIDS DENSITY INDEX (BDI)

Two variables are used to measure the settling characteristics of activated biosolids and to determine what the return biosolids pumping rate should be — the *biosolids volume index* (BVI) and the *biosolids density index* (BDI):

$$\text{BVI} = \frac{\% \text{ MLSS volume after 30 minutes}}{\% \text{ MLSS mg/L MLSS}} = \text{mL settled biosolids} \times 1000 \qquad (33.16)$$

$$\text{BDI} = \frac{\text{MLSS } (\%)}{\% \text{ volume MLSS after 30 min settling}} \times 100 \qquad (33.17)$$

These indices relate the weight of biosolids to the volume the biosolids occupies. They show how well the liquids/solids separation part of the activated biosolids system is performing its function on the biological floc that has been produced and is to be settled out and returned to the aeration tanks or wasted. The better the liquid/solids separation is, the smaller will be the volume occupied by the settled biosolids and the lower the pumping rate required to keep the solids in circulation.

**Example 33.19**

*Problem*

The settleability test indicates that after 30 minutes, 220 mL of biosolids settle in the 1-liter graduated cylinder. If the mixed liquor suspended solids (MLSS) concentration in the aeration tank is 2400 mg/L, what is the biosolids volume index?

*Solution*

Referring to Equation 33.16:

$$\text{BVI} = \frac{220 \text{ mL/L}}{2400 \text{ mg/L}}$$

$$= \frac{220 \text{ mL}}{2400 \text{ mg}}$$

After converting milligrams to grams, we have:

$$\frac{220 \text{ mL}}{2.4 \text{ g}} = 92$$

The biosolids density index (BDI) is also a method of measuring the settling quality of activated biosolids, yet, like the BVI parameter, it may or may not provide a true picture of the quality of

the biosolids in question unless it is compared with other relevant process parameters. It differs from the BVI in that the higher the BDI value, the better the settling quality of the aerated mixed liquor. Similarly, the lower the BDI, the poorer the settling quality of the mixed liquor. The BDI is the concentration in percent solids that the activated biosolids will assume after settling for 30 minutes. The BDI will range from 2.00 to 1.33, and biosolids with values of 1 or greater are generally considered to have good settling characteristics. To calculate the BDI, we simply invert the numerators and denominators and multiply by 100.

### Example 33.20

*Problem*

The MLSS concentration in an aeration tank is 2500 mg/L. If the activated biosolids settleability test indicates that 225 mL settled in the 1-liter graduated cylinder, what is the biosolids density index?

*Solution*

Referring to Equation 33.17:

$$\text{BDI} = \frac{2500 \text{ mg}}{225 \text{ mL}} \times 100$$

After converting milligrams to grams, we have:

$$\text{BDI} = \frac{2.5 \text{ g}}{225 \text{ mL}} \times 100 = 1.11$$

# *Part V*

## *Workbook Practice Problems*

# 34 Workbook Practice Problems

## TOPICS



*Note:* Answers to practice problems can be found in the Appendix.

## BASIC MATH OPERATIONS (PROBLEMS 1 TO 43)

### DECIMAL OPERATIONS

1. $90.5 \times 7.3 =$

2. $9.556 \times 1.03 =$

3. $13 \div 14.3 =$

4. $8.2 \div .96 =$

5. $2 \div .053 =$

6. Convert 3/4 into a decimal.

7. Convert 1/6 into a decimal.

8. Convert 3/8 into a decimal.

9. Convert .13 into a fraction.

10. Convert .9 into a fraction.

11. Convert .75 into a fraction.

12. Convert .245 into a fraction.

## Percentage Calculations

13. Convert 15/100 into a percent.

14. Convert 122/100 into a percent.

15. Convert 1.66 into a percent.

16. Convert 4/7 into a percent.

17. A 100% decline from 66 leaves us with how much?

## FIND $x$

18. If $x - 6 = 2$, find $x$.

19. If $x - 4 = 9$, find $x$.

20. If $x - 8 = 17$, find $x$.

21. If $x + 10 = 15$, find $x$.

22. If $x/3 = 2$, find $x$.

23. Solve for $x$ when $x/4 = 10$.

24. If $4x = 8$, find $x$.

25. If $6x = 15$, find $x$.

26. If $x + 10 = 2$, find $x$.

27. If $x - 2 = -5$, find $x$.

28. If $x + 4 = -8$, find $x$.

29. If $x - 10 = -14$, find $x$.

30. If $.5x - 1 = -6$, find $x$.

31. If $9x + 1 = 0$, find $x$.

32. How much is $x^2$ if $x = 6$?

33. If $x = 3$, find $x^4$.

34. If $x = 10$, find $x^0$.

## Ratio and Proportion

35. If an employee was out sick for 6 of 96 workdays, what is the ratio of sick days to days worked?

36. Find $x$ when $2{:}x = 5{:}15$.

## Area of Rectangles

37. What is the area of the rectangle shown in Figure 34.1?

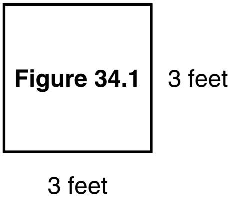


**Figure 34.1**

38. What is the area of the rectangle shown in Figure 34.2?

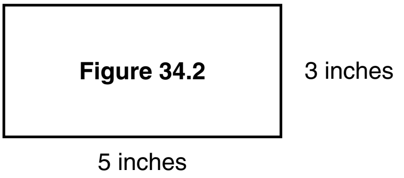

**Figure 34.2**

39. What is the area of the rectangle shown in Figure 34.3?

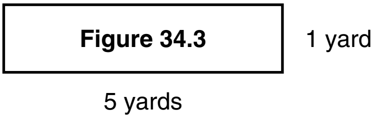

**Figure 34.3**

## Circumference and Area of Circles

40. Find the circumference of a circle with diameter of 14 ft.

41. If the circumference of a circle is 8 inches, what is the diameter?

42. If the radius of a circle is 7 inches, what is the area?

43. If the diameter of a circle is 10 inches, what is the area?

# FUNDAMENTAL OPERATIONS (WATER/WASTEWATER) (PROBLEMS 1 TO 342)

## Tank Volume Calculations

1. The diameter of a tank is 70 ft. If the water depth is 25 ft, what is the volume of water in the tank (in gallons)?

2. A tank is 60 ft in length, 20 ft wide, and 10 ft deep. Calculate the cubic foot volume of the tank.

3. A tank 20 ft wide and 60 ft long is filled with water to a depth of 12 ft. What is the volume of the water in the tank (in gal)?

4. What is the volume of water in a tank (in gallons) if the tank is 20 ft wide by 40 ft long and contains water to a depth of 12 ft?

5. A tank has a diameter of 60 ft and a depth of 12 ft. Calculate the volume of water in the tank (in gallons).

6. What is the volume of water in a tank (in gallons) if the tank is 20 ft wide by 50 ft long and contains water to a depth of 16 ft?

## Channel and Pipeline Capacity Calculations

7. A rectangular channel is 340 ft long, 4 ft deep, and 6 ft wide. What is the volume of water (in cubic feet)?

8. A replacement section of 10-inch pipe is to be sandblasted before it is put into service. If the length of pipeline is 1600 ft, how many gallons of water will be needed to fill the pipeline?

9. A trapezoidal channel is 800 ft long, 10 ft wide at the top, and 5 ft wide at the bottom, with a distance of 4 ft from the top edge to bottom along the sides. Calculate the gallon volume.

10. A section of 8-inch diameter pipeline is to be filled with treated water for distribution. If the pipeline is 2250 ft in length, how many gallons of water will be distributed?

11. A channel is 1200 ft in length, carries water 4 ft deep, and is 5 ft wide. What is the volume of water (in gallons)?

## Miscellaneous Volume Calculations

12. A pipe trench is to be excavated that is 4 ft wide, 4 ft deep, and 1200 ft long. What is the volume of the trench (in cubic yards)?

13. A trench is to be excavated that is 3 ft wide, 4 ft deep, and 500 yds long. What is the cubic yard volume of the trench?

14. A trench is 300 yards long, 3 ft wide, and 3 ft deep. What is the volume of the trench (in cubic feet)?

15. A rectangular trench is 700 ft long, 6.5 ft wide, and 3.5 ft deep. What is the volume of the trench (in cubic feet)?

16. The diameter of a tank is 90 ft. If the water depth in the tank is 25 ft, what is the volume of water in the tank (in gallons)?

17. A tank is 80 ft long, 20 ft wide, and 16 ft deep. What is the volume of the tank (in cubic feet)?

18. How many gallons of water are required to fill an 8-inch-diameter pipe that is 4000 ft in length?

19. A trench is 400 yards long, 3 ft wide, and 3 ft deep. What is the volume of the trench (in cubic feet)?

20. A trench is to be excavated. If the trench is 3 ft wide, 4 ft deep, and 1200 ft long, what is the volume of the trench (in cubic yards)?

21. A tank is 30 ft wide and 80 ft long. If the tank contains water to a depth of 12 ft, how many gallons of water are in the tank?

22. What is the volume of water (in gallons) contained in a 3000-ft section of channel if the channel is 8 ft wide and the water depth is 3.5 ft?

23. A tank has a diameter of 70 ft and a depth of 19 ft. What is the volume of water in the tank (in gallons)?

24. If a tank is 25 ft in diameter and 30 ft deep, how many gallons of water will it hold?

## Flow, Velocity, and Conversion Calculations

25. A channel 44 inches wide has water flowing to a depth of 2.4 ft. If the velocity of the water is 2.5 fps, what is the flow in the channel (in cfm)?

26. A tank is 20 ft long and 12 ft wide. With the discharge valve closed, the influent to the tank causes the water level to rise 0.8 ft in 1 minute. What is the flow to the tank (in gpm)?

27. A trapezoidal channel is 4 ft wide at the bottom and 6 ft wide at the water surface. The water depth is 40 inches. If the flow velocity through the channel is 130 ft/min, what is the flow rate through the channel (in cfm)?

28. An 8-inch diameter pipeline has water flowing at a velocity of 2.4 fps. What is the flow rate through the pipeline (in gpm)? Assume the pipe is flowing full.

29. A pump discharges into a 3-ft-diameter container. If the water level in the container rises 28 inches in 30 seconds, what is the flow into the container (in gpm)?

30. A 10-inch-diameter pipeline has water flowing at a velocity of 3.1 fps. What is the flow rate through the pipeline if the water is flowing at a depth of 5 inches (in gpm)?

31. A channel has a rectangular cross section. The channel is 6 ft wide, and water flows to a depth of 2.6 ft. If the flow rate through the channel is 14,200 gpm, what is the velocity of the water in the channel (in ft/sec)?

32. An 8-inch diameter pipe flowing full delivers 584 gpm. What is the velocity of flow in the pipeline (in ft/sec)?

33. A special dye is used to estimate the velocity of flow in an interceptor line. The dye is injected into the water at one pumping station, and the travel time to the first manhole 550 ft away is noted. The dye first appears at the downstream manhole in 195 seconds. The dye continues to be visible until the total elapsed time is 221 seconds. What is the velocity of flow through the pipeline (in ft/sec)?

34. The velocity in a 10-inch-diameter pipeline is 2.4 ft/sec. If the 10-inch pipeline flows into an 18-inch-diameter pipeline, what is the velocity in the 8-inch pipeline (in ft/sec)?

35. A float travels 500 ft in a channel in 1 minute 32 sec. What is the estimated velocity in the channel (in ft/sec)?

36. The velocity in an 8-inch-diameter pipe is 3.2 ft/sec. If the flow then travels through a 10-inch diameter section of pipeline, what is the velocity in the 10-inch pipeline (in ft/sec)?

### Average Flow Rates

37. The following flows were recorded for the week: Monday, 4.8 MGD; Tuesday, 5.1 MGD; Wednesday, 5.2 MGD; Thursday, 5.4 MGD; Friday, 4.8 MGD; Saturday, 5.2 MGD; Sunday, 4.8 MGD. What was the average daily flow rate for the week?

38. The total reading for the month of September was 121.4 MG. What was the average daily flow (ADF) for the month of September?

### Flow Conversions

39. Convert 0.165 MGD to gpm.

40. The total flow for 1 day at a plant was 3,335,000 gallons. What was the average gpm flow for that day?

41. Express a flow of 8 cfs in terms of gpm.

42. What is 35 gps expressed as gpd?

43. Convert a flow of 4,570,000 gpd to cfm.

44. What is 6.6 MGD expressed as cfs?

45. Express 445,875 cfd as gpm.

46. Convert 2450 gpm to gpd.

## General Flow and Velocity Calculations

47. A channel has a rectangular cross section. The channel is 6 ft wide with water flowing to a depth of 2.5 ft. If the flow rate through the channel is 14,800 gpm, what is the velocity of the water in the channel (in ft/sec)?

48. A channel 55 inches wide has water flowing to a depth of 3.4 ft. If the velocity of the water is 3.6 fps, what is the flow in the channel in cfm?

49. The following flows were recorded for 3 months: June, 102.4 MG; July, 126.8 MG; August, 144.4 MG. What was the average daily flow for this 3-month period?

50. A tank is 12 ft by 12 ft. With the discharge valve closed, the influent to the tank causes the water level to rise 8 inches in 1 minute. What is the rate of flow to the tank (in gpm)?

51. An 8-inch diameter pipe flowing full delivers 510 gpm. What is the velocity of flow in the pipeline (in ft/sec)?

52. Express a flow of 10 cfs in terms of gpm.

53. The total reading for the month of December was 134.6 MG. What was the average daily flow (ADF) for the month of September?

54. What is 5.2 MGD expressed as cfs?

55. A pump discharges into a 3-ft-diameter container. If the water level in the container rises 20 inches in 30 seconds, what is the rate of flow into the container (in gpm)?

56. Convert a flow of 1,825,000 gpd to cfm.

57. A 6-inch diameter pipeline has water flowing at a velocity of 2.9 fps) What is the flow rate through the pipeline (in gpm)?

58. The velocity in a 10-inch pipeline is 2.6 ft/sec. If the 10-inch pipeline flows into an 8-inch diameter pipeline, what is the velocity in the 8-inch pipeline (in feet per second)?

59. Convert 2225 gpm to gpd.

60. The total flow for 1 day at a plant was 5,350,000 gallons. What was the average gpm flow for that day?

## Chemical Dosage Calculations

61. Determine the chlorinator setting (lb/day) required to treat a flow of 5.5 MGD with a chlorine dose of 2.5 mg/L.

62. To dechlorinate a wastewater, sulfur dioxide is to be applied at a level 4 mg/L more than the chlorine residual. What should the sulfonator feed rate be (in lb/day) for a flow of 4.2 MGD with a chlorine residual of 3.1 mg/L?

63. What should the chlorinator setting be (in lb/day) to treat a flow of 4.8 MGD if the chlorine demand is 8.8 mg/L and a chlorine residual of 3 mg/L is desired?

64. A total chlorine dosage of 10 mg/L is required to treat the water in a unit process. If the flow is 1.8 MGD and the hypochlorite has 65% available chlorine, how many lb/day of hypochlorite will be required?

65. The chlorine dosage at a plant is 5.2 mg/L. If the flow rate is 6,250,000 gpd, what is the chlorine feed rate (in lb/day)?

66. A storage tank is to be disinfected with 60 mg/L of chlorine. If the tank holds 86,000 gallons, how many lb of chlorine (gas) will be needed?

67. To neutralize a sour digester, one lb of lime is to be added for every lb of volatile acids in the digester liquor. If the digester contains 225,000 gal of sludge with a volatile acid (VA) level of 2220 mg/L, how many lb of lime should be added?

68. A flow of 0.83 MGD requires a chlorine dosage of 8 mg/L. If the hypochlorite has 65% available chlorine, how many lb/day of hypochlorite will be required?

## BOD, COD, and SS Loading Calculations

69. The suspended solids concentration of wastewater entering a primary system is 450 mg/L. If the plant flow is 1,840,000 gpd, how many lb/day suspended solids enter the primary system?

70. Calculate the BOD loading (lb/day) on a stream if the secondary effluent flow is 2.90 MGD and the BOD of the secondary effluent is 25 mg/L.

71. The daily flow to a trickling filter is 5,450,000 gpd. If the BOD content of the trickling filter influent is 260 mg/L, how many lb/day BOD enter the trickling filter?

72. The flow to an aeration tank is 2540 gpm. If the COD concentration of the water is 144 mg/L, how many lb of COD are applied to the aeration tank daily?

73. The daily flow to a trickling filter is 2300 gpm with a BOD concentration of 290 mg/L. How many lb of BOD are applied to the trickling filter daily?

## BOD and SS Removal (lb/day)

74. If a primary clarifier removes 152 mg/L suspended solids, how many lb/day suspended solids are removed when the flow is 5.7 MGD?

75. The flow to a primary clarifier is 1.92 MGD. If the influent to the clarifier has a suspended solids concentration of 310 mg/L and the primary effluent has 122 mg/L SS, how many lb/day suspended solids are removed by the clarifier?

76. The flow to a primary clarifier is 1.88 MGD. If the influent to the clarifier has a suspended solids concentration of 305 mg/L and the primary effluent has 121 mg/L SS, how many lb/day suspended solids are removed by the clarifier?

77. The flow to a trickling filter is 4,880,000 gpd. If the primary effluent has a BOD concentration of 150 mg/L and the trickling filter effluent has a BOD concentration of 25 mg/L, how many lb of BOD are removed daily?

78. A primary clarifier receives a flow of 2.13 MGD with a suspended solids concentration of 367 mg/L. If the clarifier effluent has a suspended solids concentration of 162 mg/L, how many lb of suspended solids are removed daily?

79. The flow to the trickling filter is 4,200,000 gpd with a BOD concentration of 210 mg/L. If the trickling filter effluent has a BOD concentration of 95 mg/L, how many lb/day BOD does the trickling filter remove?

## Pounds of Solids Under Aeration

80. The aeration tank has a volume of 400,000 gallons. If the mixed liquor suspended solids concentration is 2230 mg/L, how many lb of suspended solids are in the aerator?

81. The aeration tank of a conventional activated sludge plant has a mixed liquor volatile suspended solids concentration of 1890 mg/L. If the aeration tank is 115 ft long by 40 ft wide and has wastewater to a depth of 12 ft, how many lb of MLVSS are under aeration?

82. The volume of an oxidation ditch is 23,800 cubic feet. If the MLVSS concentration is 3125 mg/L, how many lb of volatile solids are under aeration?

83. An aeration tank is 110 ft long and 40 ft wide. The operating depth is 16 ft. If the mixed liquor suspended solids concentration is 2250 mg/L, how many lb of mixed liquor suspended solids are under aeration?

84. An aeration tank is 105 ft long and 50 ft wide. The depth of wastewater in the tank is 16 ft. If the tank contains an MLSS concentration of 2910 mg/L, how many lb of MLSS are under aeration?

## WAS Pumping Rate Calculations

85. The WAS suspended solids concentration is 6150 mg/L. If 5200 lb/day solids are to be wasted, what must the WAS pumping rate be (in MGD)?

86. The WAS suspended solids concentration is 6200 mg/L. Assume that 4500 lb/day solids are to be wasted. (a) What must the WAS pumping rate be (in MGD)? (b) What is this rate expressed in gpm?

87. It has been determined that 6070 lb/day of solids must be removed from a secondary system. If the RAS suspended solids concentration is 6600 mg/L, what must be the WAS pumping rate (in gpm)?

88. The RAS suspended solids concentration is 6350 mg/L. If 7350 lb/day solids are to be wasted, what should the WAS pumping rate be (in gpm)?

89. A total of 5750 lb/day of solids must be removed from a secondary system. If the RAS suspended solids concentration is 7240 mg/L, what must be the WAS pumping rate (in gpm)?

90. Determine the chlorinator setting (lb/day) required to treat a flow of 3,650,000 gpd with a chlorine dose of 2.5 mg/L.

91. Calculate the BOD loading (lb/day) on a stream if the secondary effluent flow is 2.10 MGD and the BOD of the secondary effluent is 17 mg/L.

92. The flow to a primary clarifier is 4.8 MGD. If the influent to the clarifier has a suspended solids concentration of 310 mg/L and the primary effluent suspended solids concentration is 120 mg/L, how many lb/day suspended solids are removed by the clarifier?

93. What should the chlorinator setting be (lb/day) to treat a flow of 5.5 MGD if the chlorine demand is 7.7 mg/L and a chlorine residual of 2 mg/L is desired?

94. The suspended solids concentration of the wastewater entering primary system is 305 mg/L. If the plant flow is 3.5 MGD, how many lb/day suspended solids enter the primary system?

95. A total chlorine dosage of 10 mg/L is required to treat water in a unit process. If the flow is 3.1 MGD and the hypochlorite has 65% available chlorine, how many lb/day of hypochlorite will be required?

96. A primary clarifier receives a flow of 3.44 MGD with a suspended solids concentration of 350 mg/L. If the clarifier effluent has a suspended solids concentration of 140 mg/L, how many lb of suspended solids are removed daily?

97. A storage tank is to be disinfected with 60 mg/L of chlorine. If the tank holds 90,000 gallons, how many lb of chlorine gas will be needed?

98. An aeration tank is 110 ft long by 45 ft wide. The operating depth is 14 ft. If the mixed liquor suspended solids concentration is 2720 mg/L, how many lb of mixed liquor suspended solids are under aeration?

99. The WAS suspended solids concentration is 5870 mg/L. If 5480 lb/day solids are to be wasted, what must the WAS pumping rate be (in MGD)?

100. The flow to an aeration tank is 2300 gpm. If the COD concentration of the water is 120 mg/L, how many lb COD enter the aeration tank daily?

101. The daily flow to a trickling filter is 2210 gpm. If the BOD concentration of the trickling filter influent is 240 mg/L, how many lb/day BOD are applied to the trickling filter?

102. The 1.7-MGD influent to the secondary system has a BOD concentration of 220 mg/L. The secondary effluent contains 24 mg/L BOD. How many lb of BOD are removed each day by the secondary system?

103. The chlorine feed rate at a plant is 330 lb/day. If the flow is 5,300,000 gpd, what is this dosage expressed in mg/L?

104. It has been determined that 6150 lb/day solids must be removed from a secondary system. If the RAS SS concentration is 5810 mg/L, what must be the WAS pumping rate (in gpm)?

## HYDRAULIC LOADING RATE CALCULATIONS

105. A trickling filter 100 ft in diameter treats a primary effluent flow of 2.5 MGD. If the recirculated flow to the clarifier is 0.9 MGD, what is the hydraulic loading on the trickling (in gpd/sq ft)?

106. The flow to a 90-ft-diameter trickling filter is 2,850,000 gpd. The recirculated flow is 1,675,000 gpd. At this flow rate, what is the hydraulic loading rate (in gpd/sq ft)?

107. A rotating biological contactor treats a flow of 3.8 MGD. Information provided by the manufacturer indicates a media surface area of 870,000 sq ft. What is the hydraulic loading rate on the RBC (in gpd/sq ft)?

108. A pond receives a flow of 2,100,000 gpd. If the surface area of the pond is 16 acres, what is the hydraulic loading (in in./day)?

109. What is the hydraulic loading rate (in gpd/sq ft) to a 90-ft-diameter trickling filter if the primary effluent flow to the tickling filter is 3,880,000 gpd and the recirculated flow is 1,400,000 gpd?

110. A 20-acre pond receives a flow of 4.4 acre-feet/day. What is the hydraulic loading on the pond (in in./day)?

## Surface Overflow Rate Calculations

111. A sedimentation tank 70 ft by 25 ft receives a flow of 2.05 MGD. What is the surface overflow rate (in gpd/sq ft)?

112. A circular clarifier has a diameter of 60 ft. If the primary effluent flow is 2.44 MGD, what is the surface overflow rate (in gpd/sq ft)?

113. A sedimentation tank is 110 ft long and 50 ft wide. If the flow to the tank is 3.45 MGD what is the surface overflow rate (in gpd/sq ft)?

114. The primary effluent flow to a clarifier is 1.66 MGD. If the sedimentation tank is 25 ft wide by 70 ft long, what is the surface overflow rate of the clarifier (in gpd/sq ft)?

115. The flow to a circular clarifier is 2.66 MGD. If the diameter of the clarifier is 70 ft, what is the surface overflow rate (in gpd/sq ft)?

### Filtration Rate Calculations

116. A filter 40 ft by 20 ft receives a flow of 2230 gpm. What is the filtration rate (in gpm/sq ft)?

117. A filter 40 ft by 25 ft receives a flow of 3100 gpm. What is the filtration rate (in gpm/sq ft)?

118. A filter 26 ft by 60 ft receives a flow of 2500 gpm. What is the filtration rate (in gpm/sq ft)?

119. A filter 40 ft by 20 ft treats a flow of 2.2 MGD. What is the filtration rate (in gpm/sq ft)?

120. A filter has a surface area of 880 sq ft. If the flow treated is 2850 gpm, what is the filtration rate (in gpm/sq ft)?

### Backwash Rate Calculations

121. A filter 14 ft by 14 ft has a backwash flow rate of 4750 gpm. What is the filter backwash rate (in gpm/sq ft)?

122. A filter 20 ft by 20 ft has a backwash flow rate of 4900 gpm. What is the filter backwash rate (in gpm/sq ft)?

123. A filter is 25 ft by 15 ft. If the backwash flow rate is 3400 gpm, what is the filter backwash rate (in gpm/sq ft)?

124. A filter 25 ft by 30 ft backwashes at a rate of 3300 gpm. What is this backwash rate expressed as gpm/sq ft?

125. The backwash flow rate for a filter is 3700 gpm. If the filter is 15 ft by 20 ft, what is the backwash rate expressed as gpm/ft?

## Unit Filter Run Volume (UFRV) Calculations

126. The total water filtered during a filter run is 3,770,000 gallons. If the filter is 15 ft by 30 ft, what is the unit filter run volume (UFRV) (in gal/sq ft)?

127. The total water filtered during a filter run (between backwashes) is 1,860,000 gallons. If the filter is 20 ft by 15 ft, what is the unit filter run volume (UFRV) (in gal/sq ft)?

128. A filter 25 ft by 20 ft filters a total of 3.88 MG during a filter run. What is the unit filter run volume (in gal/sq ft)?

129. The total water filtered between backwashes is 1,410,200 gal. If the filter is 20 ft long and 14 ft wide, what is the unit filter run volume (in gal/sq ft)?

130. A filter is 30 ft by 20 ft. If the total water filtered between backwashes is 5,425,000 gallons, what is the UFRV (in gal/sq ft)?

## Weir Overflow Rate Calculations

131. A rectangular clarifier has a total of 163 ft of weir. What is the weir overflow rate (in gpd/ft) when the flow is 1,410,000 gpd?

132. A circular clarifier receives a flow of 2.12 MGD. If the diameter of the weir is 60 ft, what is the weir overflow rate (in gpd/ft)?

133. A rectangular clarifier has a total of 240 ft of weir. What is the weir overflow rate (in gpd/ft) when the flow is 2.7 MGD?

134. The flow rate to a clarifier is 1400 gpm. If the diameter of the weir is 80 ft, what is the weir overflow rate (in gpd/ft)?

135. A rectangular sedimentation basin has a total weir length of 189 ft. If the flow to the basin is 4.01 MGD, what is the weir-loading rate (in gpm/ft)?

## Organic Loading Rate Calculations

136. A trickling filter is 80 ft in diameter with a media depth of 5 ft. It receives a flow of 2,450,000 gpd. If the BOD concentration of the primary effluent is 210 mg/L, what is the organic loading on the trickling filter (in lb BOD/day/1000 cu ft)?

137. The flow to a 3.5-acre wastewater pond is 120,000 gpd. The influent BOD concentration is 170 mg/L. What is the organic loading to the pond (in lbs BOD/day/ac)?

138. An 85-ft-diameter trickling filter with a media depth of 6 ft receives a primary effluent flow of 2,850,000 gpd with a BOD of 120 mg/L. What is the organic loading on the trickling filter (in lb BOD/day/1000 cu ft)?

139. A rotating biological contactor (RBC) receives a flow of 2.20 MGD. If the soluble BOD of the influent wastewater to the RBC is 140 mg/L and the surface area of the media is 900,000 sq ft, what is the organic loading rate (in lb BOD/day/1000 cu ft)?

140. A 90-ft-diameter trickling filter with a media depth of 4 ft receives a primary effluent flow of 3.5 MGD. If the BOD concentration of the wastewater flow to the trickling filter is 150 mg/L, what is the organic loading rate (in lb BOD/day/1000 cu ft)?

## Food/Microorganism (F/M) Ratio Calculations

141. An activated sludge aeration tank receives a primary effluent flow of 3,420,000 gpd with a BOD of 200 mg/L. The mixed liquor volatile suspended solids concentration is 1875 mg/L and the aeration tank volume is 420,000 gallons. What is the current food-to-microorganism (F/M) ratio?

142. The volume of an aeration tank is 280,000 gallons. The amount of mixed liquor suspended solids is 1710 mg/L. If the aeration tank receives a primary effluent flow of 3,240,000 gpd with BOD of 190 mg/L, what is the F/M ratio?

143. The desired F/M ratio at a particular activated sludge plant is 0.9 lb COD/1 lb mixed liquor volatile suspended solids. If the 2.25-MGD primary effluent flow has a COD of 151 mg/L, how many lb of MLVSS should be maintained?

144. An activated sludge plant receives a flow of 2,100,000 gpd with a COD concentration of 160 mg/L. The aeration tank volume is 255,000 gallons, and the MLVSS are 1900 mg/L. What is the current F/M ratio?

145. The flow to an aeration tank is 3,110,000 gpd, with a BOD content of 180 mg/L. The aeration tank is 110 ft long by 50 ft wide and has wastewater to a depth of 16 ft. The desired F/M ratio is 0.5. What is the desired MLVSS concentration (mg/L) in the aeration tank?

## Solids Loading Rate Calculations

146. A secondary clarifier is 70 ft in diameter and receives a combined primary effluent and return-activated sludge (RAS) flow of 3.60 MGD. If the MLSS concentration in the aerator is 2650 mg/L, what is the solids loading rate on the secondary clarifier (in lb/day/sq ft)?

147. A secondary clarifier, 80 ft in diameter, receives a primary effluent flow of 3.10 MGD and a return sludge flow of 1.15 (MGD. If the MLSS concentration is 2825 mg/L, what is the solids loading rate on the clarifier (in lb/day/sq ft)?

148. The desired solids loading rate for a 60-ft-diameter clarifier is 26 lb/day/sq ft. If the total flow to the clarifier is 3,610,000 gpd, what is the desired MLSS concentration?

149. A secondary clarifier, 60 ft in diameter, receives a primary effluent flow of 2,550,000 gpd and a return sludge flow of 800,000 gpd. If the MLSS concentration is 2210 mg/L, what is the solids loading rate on the clarifier (in lb/day/sq ft)?

150. The desired solids loading rate for a 60-ft-diameter clarifier is 20 lb/day/sq ft. If the total flow to the clarifier is 3,110,000 gpd, what is the desired MLSS concentration?

## DIGESTER LOADING RATE CALCULATIONS

151. A digester receives a total of 12,110 lb/day volatile solids. If the digester volume is 33,100 cu ft, what is the digester loading in the volatile solids added/day/cu ft?

152. A digester, 60 ft in diameter with a water depth of 25 ft, receives 124,000 lb/day raw sludge. If the sludge contains 6.5% total solids with 70% volatile matter, what is the digester loading (in lb volatile solids added/day/cu ft)?

153. A digester, 50 ft in diameter with a liquid level of 20 ft, receives 141,000 lb/day sludge with 6% total solids and 71% volatile solids. What is the digester loading (in lb volatile solids added/day/cu ft)?

154. A digester, 40 ft in diameter with a liquid level of 16 ft, receives 21,200 gpd sludge with 5.5% total solids and 69% volatile solids. What is the digester loading (in lb/volatile solids/day/cu ft)? Assume the sludge weighs 8.34 lb/gal.

155. A digester, 50 feet in diameter with a liquid level of 20 ft, receives 22,000-gpd sludge with 5.3% total solids and 70% volatile solids. What is the digester loading (in lb/volatile solids/day/cu ft)? Assume the sludge weighs 8.6 lb/gal.

## DIGESTER VOLATILE SOLIDS LOADING RATIO CALCULATIONS

156. A total of 2050 lb/day volatile solids is pumped to a digester. The digester sludge contains a total of 32,400 lb of volatile solids. What is the volatile solids loading on the digester (in lb volatile solids in the digester)?

157. A digester contains a total of 174,600 lb of sludge that has a total solids content of 6.1% and volatile solids content of 65%. If 620 lb/day volatile solids are added to the digester, what is the volatile solids loading on the digester (in lb volatile solids added/day/lb volatile solids in the digester)?

158. A total of 63,200 lb/day sludge is pumped to an 115,000-gallon digester. The sludge being pumped to the digester has a total solids content of 5.5% and a volatile solids content of 73%. The sludge in the digester has a total solids content of 6.6% with a 59% volatile solids content. What is the volatile solids loading on the digester (in lb volatile solids added/day/lb VS in the digester)? Assume the sludge in the digester weighs 8.34 lb/gal.

159. A total of 110,000 gal of digested sludge is in a digester. The digested sludge contains 5.9% total solids and 58% volatile solids. If the desired volatile solids loading ratio is 0.08 lb volatile solids added/day/lb volatile solids under digestion, what is the desired lb volatile solids/day to enter the digester? Assume the sludge in the digester weighs 8.34 lb/gal.

160. A total of 7900 gpd sludge is pumped to the digester. The sludge has 4.8% solids with a volatile solids content of 73%. If the desired volatile solids loading ratio is 0.06 lb volatile solids added/day/lb volatile solids under digestion, how many lb volatile solids should be in the digester for this volatile solids load? Assume the sludge pumped to the digester weighs 8.34 lb/gal.

## Population Loading and Population Equivalent

161. A 5.3-acre wastewater pond serves a population of 1733. What is the population loading on the pond (in persons per acre)?

162. A wastewater lb serves a population of 4112. If the pond is 10 acres, what is the population loading on the pond?

163. A 381,000 gpd wastewater flow has a BOD concentration of 1765 mg/L. Using an average of 0.2 lb/day BOD/person, what is the population equivalent of this wastewater flow?

164. A wastewater lb is designed to serve a population of 6000. If the desired population loading is 420 persons per acre, how many acres of pond will be required?

165. A 100,000 gpd wastewater flow has a BOD content of 2210 mg/L. Using an average of 0.2 lb/day BOD/person, what is the population equivalent of this flow?

## General Loading Rate Calculations

166. A circular clarifier has a diameter of 80 ft. If the primary effluent flow is 2.25 MGD, what is the surface overflow rate (in gpd/sq ft)?

167. A filter has an area of 190 sq ft. If the flow rate to the filter is 2960 gpm, what is this filter backwash rate expressed as gpm/sq ft?

168. The flow rate to a circular clarifier is 2,100,000 gpd. If the diameter of the weir is 80 ft, what is the weir overflow rate (in gpd/ft)?

169. A trickling filter, 90 ft in diameter, treats a primary effluent flow of 2.8 MGD. If the recirculated flow to the clarifier is 0.5 MGD, what is the hydraulic loading on the trickling filter (in gpd/sq ft)?

170. The desired F/M ratio at an activated sludge plant is 0.7 lb BOD/day/lb mixed liquor volatile suspended solids. If the 2.1-MGD primary effluent flow has a BOD of 161 mg/L, how many lb of MLVSS should be maintained in the aeration tank?

171. A digester contains a total of 182,000 lb sludge that has a total solids content of 6.4% and volatile solids of 67%. If 500 lb/day volatile solids are added to the digester, what is the volatile solids loading on the digester (in lb/day volatile solids added per lb volatile solids in the digester)?

172. A secondary clarifier is 80 ft in diameter and receives a combine primary effluent and return-activated sludge (RAS) flow of 3.58 MGD. If the MLSS concentration in the aerator is 2760 mg/L, what is the solids loading rate on the secondary clarifier (in lb/day/sq ft)?

173. A digester, 70 ft in diameter with a water depth of 21 ft, receives 115,000 lb/day raw sludge. If the sludge contains 7.1% solids with 70% volatile solids, what is the digester loading (in lb volatile solids added/day/cu ft volume)?

174. A 25-acre pond receives a flow of 4.15 acre-feet/day. What is the hydraulic loading on the pond (in in./day)?

175. The flow to an aeration tank is 3,335,000 gpd with a BOD content of 174 mg/L. The aeration tank is 80 ft long by 40 ft wide and has wastewater to a depth of 12 ft, The desired F/M ratio is 0.5. What is the desired MLVSS concentration (in mg/L) in the aeration tank?

176. A sedimentation tank 80 ft by 25 ft receives a flow of 2.0 MGD. What is the surface overflow rate (in gpd/da ft)?

177. The total water filtered during a filter run (between backwashes) is 1,785,000 gallons. If the filter is 25 ft by 20 ft, what is the unit filter run volume (UFRV) (in gal/sq ft)?

178. The volume of an aeration tank is 310,000 gallons. The mixed liquor volatile suspended solids concentration is 1920 mg/L. If the aeration tank receives a primary effluent flow of 2,690,000 gpd with a COD of 150 mg/L, what is the F/M ratio?

179. A total of 24,500 gallons of digested sludge is in a digester. The digested sludge contains 5.5% solids and 56% volatile solids. To maintain a desired volatile loading ratio of 0.09 lb volatile solids added/day/lb volatile solids under digestion, what is the desired lb volatile solids/day loading to the digester?

180. The flow to a filter is 4.44 MGD. If the filter is 40 ft by 30 ft, what is the filter-loading rate (in gpm/sq ft)?

181. An 80-ft-diameter trickling filter with a media depth of 4 ft receives a primary effluent flow of 3.3 MGD with a BOD concentration of 115 mg/L. What is the organic loading on the filter (in lb BOD/day/1000 cu ft)?

182. A circular clarifier receives a flow of 2.56 MGD. If the diameter of the weir is 80 ft, what is the weir overflow rate (in gpd/ft)?

183. A 5.5-acre wastewater pond serves a population of 1900. What is the population loading on the pond (people/acre)?

184. A rotating biological contactor (RBC) receives a flow of 2.44 MGD. If the soluble BOD of the influent wastewater to the RBC is 140 mg/L and the surface area of the media is 750,000 sq ft, what is the organic loading rate (in lb soluble BOD per day per 1000 sq ft)?

185. A filter 40 ft by 30 ft treats a flow of 4.15 MGD. What is the filter-loading rate (in gpm/sq ft)?

## Detention Time Calculations

186. A flocculation basin is 8 ft deep, 16 ft wide, and 30 ft long. If the flow through the basin is 1.45 MGD, what is the detention time (in minutes)?

187. The flow to a sedimentation tank that is 80 ft long, 20 ft wide, and 12 ft deep is 1.8 MGD. What is the detention time in the tank (in hours)?

188. A basin 3 ft by 4 ft is to be filled to the 3-ft level. If the flow to the tank is 6 gpm, how long will it take to fill the tank (in hours)?

189. The flow rate to a circular clarifier is 5.20 MGD. If the clarifier is 80 ft in diameter with water to a depth of 10 ft, what is the detention time (in hours)?

190. A waste treatment pond is operated at a depth of 6 ft. The average width of the pond is 500 ft and the average length is 600 ft. If the flow to the pond is 222,500 gpd, what is the detention time (in days)?

## Sludge Age Calculations

191. An aeration tank has a total of 12,300 lb of mixed liquor suspended solids. If 2750 lb/day suspended solids enter the aerator in the primary effluent flow, what is the sludge age in the aeration tank?

192. An aeration tank is 110 ft long by 30 ft wide with wastewater to a depth of 20 ft. The mixed liquor suspended solids concentration is 2820 mg/L. If the primary effluent flow is 988,000 gpd with a suspended solids concentration of 132 mg/L, what is the sludge age in the aeration tank?

193. An aeration tank contains 200,000 gallons of wastewater. The MLSS concentration is 2850 mg/L. If the primary effluent flow is 1.52 MGD with a suspended solids concentration of 84 mg/L, what is the sludge age?

194. The 2.10-MGD primary effluent flow to an aeration tank has a suspended solids concentration of 80 mg/L. The aeration tank volume is 205,000 gallons. If a sludge age of 6 days is desired, what is the desired MLSS concentration?

195. A sludge age of 5.5 days is desired. Assume that 1610 lb/day suspended solids enter the aeration tank in the primary effluent. To maintain the desired sludge age, how many lb of MLSS must be maintained in the aeration tank?

## Solids Retention Time (SRT) Calculations

196. An aeration tank has a volume of 320,000 gallons. The final clarifier has a volume of 180,000 gallons. The MLSS concentration in the aeration tank is 3300 mg/L. If 1610 lb/day suspended solids are wasted and 340 lb/day suspended solids are in the secondary effluent, what is the solids retention time for the activated sludge system? Use the solids retention equation that uses combined aeration tank and final clarifier volumes to estimate system solids.

197. Determine the solids retention time (SRT) given the data provided. Use the SRT equation that uses combined aeration tank and final clarifier volumes to estimate system solids. *Aerator volume*, 250,000 gal; *MLSS*, 2750 mg/L; *final clarifier volume*, 110,000 gal; *WAS SS*, 5410 mg/L; *WAS pumping rate*, 19,200 gpd; *population estimate flow*, 2.35 MGD; *secondary effluent SS*, 16 mg/L.

198. Calculate the solids retention time given the data provided. Use the SRT equation that uses combined aeration tank and final clarifier volumes to estimate system solids. *Aerator tank volume*, 1.4 MG; *MLSS*, 2550 mg/L; *final clarifier volume*, 0.4 MG; *WAS SS*, 6240 mg/L; *WAS pumping rate*, 85,000 gpd; *population equivalent flow*, 2.8 MGD; *secondary effluent SS*, 20 mg/L.

199. The volume of an aeration tank is 800,000 gal and the final clarifier is 170,000 gal. The desired solids retention time (SRT) for the plant is 8 days. The primary effluent flow is 2.6 MGD and the WAS pumping rate is 32,000 gpd. If the WAS SS concentration is 6340 mg/L and the secondary effluent SS concentration is 20 mg/L, what is the MLSS concentration (in mg/L)?

## General Detention Time and Retention Time Calculations

200. The flow to a sedimentation tank that is 75 ft long, 30 ft wide, and 14 ft deep is 1,640,000 gpd. What is the detention time in the tank (in hours)?

201. An aeration tank has a total of 12,600 lb of mixed liquor suspended solids (MLSS). If 2820 lb/day suspended solids enter the aeration tank in the primary effluent flow, what is the sludge age in the aeration tank?

202. An aeration tank has a volume of 310,000 gallons. The final clarifier has a volume of 170,000 gallons. The MLSS concentration in the aeration tank is 3120 mg/L. If 1640 lb/day suspended solids are wasted and 320 lb/day suspended solids are in the secondary effluent, what is the solids retention time for the activated sludge system?

203. The flow through a flocculation basin is 1.82 MGD. If the basin is 40 ft long, 20 ft wide, and 10 ft deep, what is the detention time (in minutes)?

204. Determine the solids retention time given the data provided. *Aeration volume*, 220,000 gal; *MLSS*, 2810 mg/L; *final clarifier volume*, 115,000 gal; *WAS SS*, 6100 mg/L; *WAS pumping rate*, 18,900 gpd; *population equivalent flow*, 2,400,000 gpd; secondary effluent SS, 18 mg/L.

205. The mixed liquor suspended solids concentration in an aeration tank is 3250 mg/L. The aeration tank contains 330,000 gallons. If the primary effluent flow is 2,350,000 gpd with suspended solids concentrations of 100 mg/L, what is the sludge age?

206. Calculate the solids retention time given the data provided. *Aeration tank volume*, 1.5 MG; *MLSS*, 2408 mg/L; *final clarifier volume*, 0.4 MG; *WAS SS*, 6320 mg/L; *WAS pumping rate*, 71,200 gpd; *population equivalent flow*, 2.85 MGD; *secondary effluent SS*, 25 mg/L.

207. An aeration tank is 80 ft long by 25 ft wide with a wastewater to a depth of 10 ft. The mixed liquor suspended solids concentration is 2610 mg/L. If the influent flow to the aeration tank is 920,000 gpd with a suspended solids concentration of 140 mg/L, what is the sludge age in the aeration tank?

208. A tank 6 ft in diameter is to be filled to the 4-ft level. If the flow to the tank is 12 gpm, how long will it take to fill the tank (in minutes)?

209. A sludge age of 6 days is desired. The suspended solids concentration of the 2.14-MGD influent flow to the aeration tank is 140 mg/L. To maintain the desired sludge age, how many lb of MLSS must be maintained in the aeration tank?

210. The average width of a pond is 400 ft and the average length is 440 ft. The depth is 6 ft. If the flow to the pond is 200,000 gpd, what is the detention time (in days)?

211. The volume of an aeration tank is 480,000 gal and the volume of the final clarifier is 160,000 gal. The desired solids retention time for the plant is 7 days. The primary effluent flow is 2,920,000 gpd and the WAS pumping rate is 34,000 gpd. If the WAS SS concentration is 6310 mg/L, and the secondary effluent SS concentration is 12 mg/L, what is the desired MLSS concentration (in mg/L)?

## Efficiency and General Percent Calculations

212. The suspended solids concentration entering a trickling filter is 110 mg/L. If the suspended solids concentration in the trickling filter effluent is 21 mg/L, what is suspended solids removal efficiency of the trickling filter?

213. The BOD concentration of the raw wastewater at an activated sludge plant is 230 mg/L. If the BOD concentration of the final effluent is 14 mg/L, what is the overall efficiency of the plant in BOD removal?

214. The influent flow to a waste treatment pond has a BOD content of 260 mg/L. If the pond effluent has a BOD content of 60 mg/L, what is the BOD removal efficiency of the pond?

215. The suspended solids concentration of a primary clarifier influent is 310 mg/L. If the suspended solids concentration of the primary effluent is 135 mg/L, what is the suspended solids removal efficiency?

## Percent Solids and Sludge Pumping Rate Calculations

216. A total of 3700 gallons of sludge is pumped to a digester. If the sludge has a 4.9% solids content, how many lb/day solids are pumped to the digester? Assume the sludge weighs 8.34 lb/gal.

217. The total weight of a sludge sample is 12.87 grams (sample only, not the dish). If the weight of the solids after drying is 0.87 grams, what is the percent total solids of the sludge?

218. A total of 1450 lb/day suspended solids is removed from a primary clarifier and pumped to a sludge thickener. If the sludge has a solids content of 3.3%, how many lb/day sludge is this?

219. It is anticipated that 258 lb/day suspended solids will be pumped from the primary clarifier of a new plant. If the primary clarifier sludge has a solids content of 4.4%, how many gpd sludge will be pumped from the clarifier? Assume a sludge weight of 8.34 lb/gal.

220. A total of 291,000 lb/day sludge is pumped from a primary clarifier to a sludge thickener. If the total solids content of the sludge is 3.6%, how many lb/day total solids are sent to the thickener?

221. A primary sludge flow of 3100 gpd with a solids content of 4.4% is mixed with a thickened secondary sludge flow of 4100 gpd that has a solids content of 3.6%. What is the percent solids content of the mixed sludge flow? Assume the density of both sludges is 8.34 lb/gal.

222. Primary and thickened secondary sludges are to be mixed and sent to the digester. The 8100 gpd primary sludge has a solids content of 5.1%, and the 7000-gpd thickened secondary sludge has a solids content of 4.1%. What would be the percent solids content of the mixed sludge? Assume the density of both sludges is 8.34 lb/gal.

223. A 4750 gpd primary sludge has a solids content of 4.7%. The 5250-gpd thickened secondary sludge has a solids content of 3.5%. If the sludges were blended, what would be the percent solids content of the mixed sludge? Assume the density of both sludges is 8.34 lb/gal.

224. A primary sludge flow of 8925 gpd with a solids content of 4.0% is mixed with a thickened secondary sludge flow of 11,340 gpd with 6.6% solids content. What is the percent solids of the combined sludge flow? Assume the density of both sludges is 8.34 lb/gal.

## Percent Volatile Solids Calculations

225. If 3250 lb/day solids with a volatile solids content of 65% are sent to a digester, how many lb/day volatile solids are sent to the digester?

226. A total of 4120 gpd of sludge is to be pumped to the digester. If the sludge has 7% solids content with 70% volatile solids, how many lb/day volatile solids are pumped to the digester? Assume the sludge weighs 8.34 lb/gal.

227. How many lb/day volatile solids are pumped to the digester if 6600 gpd of sludge are to be pumped to the digester? The sludge has a 6.6% solids content, of which 66% is volatile solids. Assume the sludge weighs 8.34 lb/gal.

228. A 6.6% sludge has a volatile solids content of 64%. If 23,650 lb/day of sludge are pumped to the digester, how many lb/day of volatile solids are pumped to the digester?

229. A sludge has a solids content of 6.0% and a volatile solids content of 70%. If 2560 gpd of sludge are pumped to the digester, how many lb/day volatile solids are pumped to the digester? Assume the sludge weighs 8.34 lb/gal.

## Seed Sludge Calculations

230. A digester has a capacity of 290,000 gallons. If the digester seed sludge is to be 16% of the digester capacity, how many gallons of seed sludge will be required?

231. A digester 80 ft in diameter has a sidewall water depth of 20 ft. If the digester seed sludge is to be 20% of the digester capacity, how many gallons of seed sludge will be required?

232. A 60-ft-diameter digester has a typical water depth of 20 ft. If the seed sludge to be used is 14% of the tank capacity, how many gallons of seed sludge will be required?

233. A 70-ft-diameter digester has a typical sidewall water depth of 22 ft. If 88,350 gallons of seed sludge are to be used in starting up the digester, what percent of the digester volume will be seed sludge?

## Solution Strength Calculations

234. A total of 3 lb of chemical is dissolved in 90 lb of solution. What is the percent strength, by weight, of the solution?

235. If 6 ounces of dry polymer are added to 10 gallons of water, what is the percent strength (by weight) of the polymer solution?

236. How many lb of dry polymer must be added to 60 gallons of water to make a 1.7% (by weight) polymer solution?

237. If 600 grams of dry polymer are dissolved in 9 gallons of water, what percent strength is the solution? (1 gram = 0.0022 lb)

238. How many grams of chemical must be dissolved in 6 gallons of water to make a 1.9% solution? (1 lb = 454 grams)

239. If 16 lb of a 10% strength solution are mixed with 110 lb of a 1% strength solution, what is the percent strength of the solution mixture?

240. If 12 lb of a 14% strength solution are mixed with 350 lb of a 0.5% strength solution, what is the percent strength of the solution mixture?

241. If 22 lb of a 12% strength solution are mixed with 440 lb of a 0.5% strength solution, what is the percent strength of the solution mixture?

242. If 12 gallons of a 12% strength solution are added to 70 gallons of a 0.1% strength solution, what is the percent strength of the solution mixture? Assume the 12% strength solution weighs 9.9 lb/gal and the 0.1% strength solution weighs 8.34 lb/gal.

## Pump and Motor Efficiency Calculations

243. Calculate the brake horsepower (bhp) requirements for a pump handling saltwater and having a flow of 600 gpm with 40 psi differential pressure. The specific gravity of salt water at 68˚F is equal to 1.03. The pump efficiency is 85%. The total differential head (TDH) is 90 ft.

244. A pump has a water horsepower (whp) requirement of 8.5 whp. If the motor supplies the pump with 12 hp, what is the efficiency of the pump?

245. What is the efficiency if electric power equivalent to 25 hp is supplied to the motor and 14 hp of work is accomplished by the pump?

246. Twelve kW (kilowatts) of power are supplied to the motor. If the brake horsepower is 14 hp, what is the efficiency of the motor?

247. The brake horsepower of a pump is 20 hp. If the water horsepower is 18 hp, what is the efficiency of the pump?

248. If the motor horsepower is 40 hp and the brake horsepower is 38 hp, what is the efficiency of the motor?

249. The motor horsepower (mhp) is 22 hp. If the motor is 88% efficient, what is the brake horsepower (bhp)?

250. A total of 60 hp is supplied to a motor. If the wire-to-water efficiency of the pump and motor is 60%, what will the whp be?

251. The brake horsepower (bhp) is 35.5 hp. If the motor is 88% efficient, what is the motor horsepower?

## General Efficiency and Percent Calculations

252. The BOD concentration of the raw wastewater at an activated sludge plant is 240 mg/L. If the BOD concentration of the final effluent is 18 mg/L, what is the overall efficiency of the plant in BOD removal?

253. A total of 7400 gpd sludge is to be pumped to the digester. If the sludge has a 6% solids content with 66% volatile solids, how many lb/day volatile solids are pumped to the digester? Assume the sludge weighs 8.34 lb/gal.

254. A primary sludge flow of 2500 gpd with a solids content of 4.0% is mixed with a secondary sludge flow of 3270 gpd with a solids content of 3.8%. What is the percent solids content of the mixed sludge flow? Assume the weight of both sludges is 8.34 lb/gal.

255. A total of 3 lb of chemical has been dissolved in 96 lb of solution. What is the percent strength, by weight, of the solution?

256. A digester 90 ft in diameter has a sidewall water depth of 34 ft. If the digester seed sludge is to be 21% of the digester capacity, how many gallons of seed sludge will be required?

257. If 10 lb of a 12% strength solution are mixed with 500 lb of a 0.15% strength solution, what is the percent strength of the solution mixture?

258. The brake horsepower (bhp) of a pump is 26.5 hp. If the water horsepower is 21.5 hp, what is the efficiency of the pump?

259. The influent flow to a waste treatment pond has a BOD content of 340 mg/L. If the pond effluent has a BOD content of 83 mg/L, what is the BOD removal efficiency of the pond?

260. A primary sludge flow of 8800 gpd with a solids content of 4.6% is mixed with a thickened secondary sludge flow of 11,300 gpd with a solids content of 6.0%. What is the percent solids of the combined sludge flow? Assume the weight of both sludges is 8.34 lb/gal.

261. How many lb/day volatile solids are pumped to the digester if 7300 gpd of the sludge are pumped to the digester? The sludge has a 6.0% solids content, of which 70% is volatile solids.

262. A total of 36,100 lb/day of sludge is pumped to the digester, If the sludge has a solids content of 5.8%, how many lb/day solids are pumped to the digester?

263. How many lb of dry polymer must be added to 70 gallons of water to make a 0.5% polymer solution?

264. A digester has a capacity of 200,000 gallons. If the digester seed sludge is to be 26% of the digester capacity, how many gallons of seed sludge will be required?

265. If 7100 lb/day solids with a volatile solids content of 70% are pumped to the digester, how many lb/day volatile solids are pumped to the digester?

266. If 9 lb of an 8% strength solution are mixed with 80 lb of a 1% strength solution, what is the percent strength of the solution mixture?

267. If the motor horsepower (mhp) is 40 hp and the brake horsepower (bhp) is 28 hp, what is the efficiency of the motor?

268. A total of 80 horsepower is supplied to a motor. If the wire-to-water efficiency of the pump and motor is 68%, what will the water horsepower (whp) be?

## Pumping Calculations

269. If enough air was removed from the tube to produce an air pressure of 9.7 lb per square inch (psi) above the water in the tube, how far will the water rise in the tube?

270. What is the pressure (in lb per square inch) at a point 15 ft below the surface of a reservoir?

271. Water in an open reservoir is subjected to the 14.7 lb per square inch (psi) of atmospheric pressure, but subtracting this 14.7 psi of atmospheric pressure leaves a gauge pressure of 0 psi. This shows that the water would rise 0 ft above the reservoir surface. If the gauge pressure in a water main is 100 psi, how far would the water rise in a tube connected to the main?

272. A pipe 12 inches in diameter has water flowing through it at 10 ft per second (fps). What is the discharge in (a) cubic feet per second (cfs), (b) gpm, and (c) MGD?

273. A pipe 12 inches in diameter is connected to a 6-inch-diameter pipe. The velocity of the water in 12-inch pipe is 3 ft per second (fps). What is the velocity in the 6-inch pipe? Using the equation $A_1V_1 = A_2V_2$, determine the area of each pipe.

274. During a 15-minute pumping test, 16,400 gallons are pumped into an empty rectangular tank. What is the pumping rate (in gpm)?

275. A tank 50 ft in diameter is filled with water to a depth of 4 ft. To conduct a pumping test, the outlet valve to the tank is closed, and the pump is allowed to discharge into the tank. After 80 minutes, the water level is 5.5 ft. What is the pumping rate (in gpm)?

## Density and Specific Gravity

276. A gallon of solution is weighed. After the weight of the container is subtracted, it is determined that the weight of the solutions is 9.1 lb. What is the density of the solution?

277. The density of a substance is give as 66.3 lb per cubic foot. What is this density expressed as lb/gal?

278. The density of a liquid is given as 56 lb per cubic feet. What is the specific gravity of the liquid?

279. Suppose a piece of metal weighs 150 lb in air and 85 lb under water. What is the specific gravity?

280. A basin contains 1455 gallons of a certain liquid. If the specific gravity of the liquid is 0.94, how many lb of liquid are in the basin?

281. The specific gravity of a liquid is 1.4. What is the density of that liquid? The density of water is 8.34 lb/gal.

282. We wish to determine the specific gravity of a solution. After weighing a gallon of the solution and subtracting the weight of the container, the solution is found to weigh 9.1 lb. What is the specific gravity of the solution?

## Force and Pressure Calculations

283. A tank is mounted at a height of 90 ft. Find the pressure at the bottom of the tank.

284. Find the height of water in a tank if the pressure at the bottom of the tank is 22 lb per square inch (psi).

285. A container 3 ft long, 2 ft wide, and 0.6 ft deep weighs 85 lb. What is the lb per square inch (psi) pressure at the surface of contact?

286. An object rests on the floor. The pressure at the surface of contact is 2.8 lb per square inch (psi). If the object is placed on another side that has only one fourth the contact area, what is the new lb per square inch pressure?

287. What is the pressure (in lb per square foot) at a point 8 ft below the surface of a water? The density of water is 62.4 lb per cubic foot.

288. What is the pressure (in lb per square inch) at a point 9 ft below the surface?

289. At a point 5 ft below the surface of a liquid, what is the pressure in lb per square inch (psi)? The specific gravity of the liquid is 1.4.

290. What is the total force against the bottom of a tank 30 ft long and 14 ft wide? The water depth is 12 ft.

291. What is the total force exerted on the side of a tank if the tank is 30 ft wide and the water depth is 12 ft?

292. The side of a tank is 16 ft wide. The water depth is 10 ft. At what depth is the center of force against the tank wall?

293. The force applied to the small cylinder of a hydraulic jack is 60 lb. The diameter of the small cylinder is 8 inches. If the diameter of the large cylinder is 2.5 ft, what is the total lifting force?

294. A gauge reading is 30 lb per square inch (psi). What is the absolute pressure at the gauge (at sea level)?

## Head and Head Loss Calculations

295. A supply tank is located at elevation 118 ft. The discharge point is at elevation 215 ft. What is the static head (in feet)?

296. The pressure gauge on the discharge line from an influent pump reads 72.3 lb per square inch (psi). What is the equivalent head (in feet)?

297. The elevations of two water surfaces are 320 ft and 241 feet. What is the total static head (in feet)?

298. The elevations of two water surfaces are 780 ft and 624 ft. If the friction and minor head losses equal 18 ft, what is the total dynamic head (in feet)?

## Horsepower Calculations

299. A pump must pump 1600 gpm against a total head of 50 ft. What horsepower is required for this work?

300. If 25 horsepower (hp) is supplied to a motor (mhp), what is the brake horsepower (bhp) and water horsepower (whp) if the motor is 80% efficient and the pump is 75% efficient?

301. A total of 40 horsepower (hp) is required for a particular pumping application. If the pump efficiency is 80%, what is the brake horsepower (bhp) required?

302. A pump must pump against a total dynamic head of 70 ft at a flow rate of 700 gpm. The liquid to be pumped has a specific gravity of 1.3. What is the water horsepower (whp) requirement for this pumping application?

303. A motor horsepower (mhp) requirement has been calculated to be 50 hp. How many kilowatts electric power does this represent? (1 hp = 746 watts)

304. The motor horsepower (mhp) requirement has been calculated to be 80 hp. During the week, the pump is in operation a total of 148 hours. Using a power cost of $0.05951 per kilowatt hour (kWh), what would be the power cost that week for the pumping?

## Pump Capacity Calculations

305. A wet well is 10 ft long and 8 ft wide. The influent valve to the wet well is closed. If a pump lowers the water level 2.1 feet during a 5-minute pumping test, what is the gpm pumping rate?

306. A pump discharged into a 55-gallon barrel. If it takes 32 seconds to fill the barrel, what is the pumping rate?

307. A pump test is conducted for 5 minutes while influent flow continues. During the test, the water level rises 3 inches. If the tank is 9 ft by 12 ft and the influent flow is 500 gpm, what is the pumping rate (in gpm)?

308. A piston pump discharges a total of 0.80 gallons per stroke. If the pump operates at 30 strokes per minute, what is the gpm pumping rate? Assume the piston is 100% efficient and displaces 100% of its volume each stroke.

309. A sludge pump has a bore of 8 inches and a stroke setting of 3 inches. The pump operates at 35 strokes per minute. If the pump operates a total of 140 minutes during a 24-hour period, what is the gpd pumping rate? Assume the piston is 100% efficient.

## General Pumping Calculations

310. What is the height of a column of water that produces 22 lb per square inch (psi)?

311. What is the pressure at a point 16 ft below the surface of a water storage tank?

312. Calculate the brake horsepower (bhp) requirements for a pump handling saltwater and having a flow of 800 gpm with a 30-psi differential pressure. The specific gravity of the saltwater at 68˚F is 1.03. The pump efficiency is 70%.

313. A pump has a water horsepower (whp) requirement of 9.0 whp. If the motor supplies the pump with 10 hp, what is the efficiency of the pump?

314. The density of a substance is given at 68 lb per cubic foot. What is the density expressed as lb/gal?

315. The dimensions of a wet well are 14 ft by 10 ft. The influent valve to the wet well is closed. If a pump lowers the water level 1.5 ft during a 5-minute pumping test, what is the gpm capacity of the pump?

316. A sludge pump has a bore of 6 inches and a stroke of 3 inches. If the pump operates at 60 strokes per minute, how many gpm are pumped? Assume the piston is 100% efficient and displaces 100% of its volume each stroke.

317. A pump must pump 800 gpm against a total head of 60 ft. What horsepower is required for this work?

318. A sludge pump has a bore of 8 inches and a stroke setting of 3.5 inches. The pump operates at 55 revolutions per minute. If the pump operates a total of 120 minutes during a 24-hour period, what is the gpd pumping rate? Assume the piston is 100% efficient.

319. The specific gravity of a liquid is 1.5. What is the density of that liquid? The density of water is 8.34 lb/gal.

320. The elevations of two water surfaces are 848 ft and 766 ft. If the friction and minor head losses equal 10 ft, what is the total dynamic head (in feet)?

321. What is the total force exerted on the side of a tank if the tank is 16 ft wide and the water depth is 11 feet?

322. If 60 horsepower (hp) is supplied to a motor, what is the brake horsepower (bhp) and water horsepower (whp) if the motor is 92% efficient and the pump is 88% efficient?

## Basic Electricity Calculations

323. In a simple series circuit, a 6-ohm resister is connected to a voltage source of 3 volts. How much current flows in the circuit?

324. In a simple series circuit, a 6-ohm resister is connected to a voltage source of 6 volts. How much current flows in the circuit?

325. A simple series circuit contains a voltage source of 3 volts and a total resistance of 12 ohms. How much current flows in the circuit?

326. Find $E$ when $I = 2.5$ amperes and $R = 25$ ohms.

327. Find $R$ when $E = 220$ volts and $I = 10$ amperes.

328. An electric light bulb draws 0.5 amperes (A) when operating on a 120-volt (V) D-C circuit. What is the resistance of the bulb?

329. The current through a 200-ohm resistor to be used in a circuit is 0.25 amperes (A). Find the power rating of the resistor.

330. How many kilowatts (kW) of power are delivered to a circuit by a 220-volt (V) generator that supplies 30 amperes (A) to the circuit?

331. If the voltage across a 30,000-ohm resistor is 450 volts (V), what is the power dissipated in the resistor?

332. How much energy is delivered in 4 hours by a generator supplying 12 kilowatts (kW)?

333. Three resistors of 10 ohms, 12 ohms, and 25 ohms are connected in series across a battery for which the electromagnetic force (emf) is 110 volts (V). What is the total resistance?

334. The total resistance of a circuit containing three resistors is 50 ohms. Two of the circuit resistors are 12 ohms each. Calculate the value of the third resistor.

335. A series circuit consists of three resistors having values of 10 ohms, 20 ohms, and 40 ohms. Find the applied voltage if the current through the 20-ohm resistor is 2.5 amperes (A).

336. A series circuit consists of three resistors having values of 5 ohms, 15 ohms, and 20 ohms. Find the total power dissipation when 120 volts (V) is applied to the circuit.

337. Assume that the current through a resistor of a parallel circuit is known to be 4.0 milliamperes (mA), and the value of the resistor is 40,000 ohms. Determine the potential (voltage) across the resistor.

338. Two resistors each drawing 2 amperes (A) and a third resistor drawing 1 A are connected in parallel across a 100-volt (V) line. What is the total current?

339. Five 50-ohm resistors are connected in parallel. What is the equivalent circuit resistance?

340. What is the equivalent resistance of a 20-ohm and a 30-ohm resistor connected in parallel?

341. A number 12 wire has a diameter of 80.81 mils. What is its area in circular mils and in square mils?

342. Calculate the ampere-turns for a coil with 2000 turns and a 5-mA current.

## WATER TREATMENT CALCULATIONS (PROBLEMS 1 TO 457)

### Water Sources and Storage Calculations: Well Drawdown

1. The static water level for a well is 91 feet. If the pumping water level is 98 ft, what is the well drawdown?

2. The static water level for a well is 110 ft. The pumping water level is 125 ft. What is the well drawdown?

3. Before the pump is started, the water level is measured at 144 ft. The pump is then started. If the pumping water level is determined to be 161 feet, what is the well drawdown?

4. The static water level of a well is 86 ft. The pumping water level is determined using a sounding line. The air pressure applied to the sounding line is 3.7 lb per square inch (psi) and the length of the sound line is 112 ft. What is the drawdown?

5. A sounding line is used to determine the static water level for a well. The air pressure applied to 4.6 lb per square inch (psi) and the length of the sounding line is 150 ft. If the pumping water level is 171 feet, what is the drawdown?

## Well Yield

6. If a well yield is 300 gpm and the drawdown is measured to be 20 ft, what is the specific capacity?

7. During a 5-minute well yield test, a total of 420 gallons was pumped from the well. What is the well yield (in gpm)?

8. When the drawdown of a well stabilized, it was determined that the well produced 810 gallons during a 5-minute pumping test. What is the well yield (in gpm)?

9. During a test for well yield, a total of 856 gallons was pumped from the well. If the well yield test lasted 5 minutes, what was the well yield in gpm? In gph?

10. A bailer is used to determine the approximate yield of a well. The bailer is 12 ft long and has a diameter of 12 inches. If the bailer is placed in the well and removed a total of 12 times during a 5-minute test, what is the well yield (in gpm)?

11. During a 5-minute well yield test, a total of 750 gallons of water was pumped from the well. At this yield, if the pump is operated a total of 10 hours each day, how many gallons of water are pumped daily?

## Specific Yield

12. The discharge capacity of a well is 200 gpm. If the drawdown is 28 ft, what is the specific yield in gallons per minute per foot of drawdown?

13. A well produces 620 gpm. If the drawdown for the well is 21 feet, what is the specific yield in gallons per minute per foot of drawdown?

14. A well yields 1100 gpm. If the drawdown is 41.3 ft, what is the specific yield in gallons per minute per foot of drawdown?

15. The specific yield of a well is listed as 33.4 gpm per foot. If the drawdown for the well is 42.8 ft, what is the well yield (in gpm)?

## Well Casing Disinfection

16. A new well is to be disinfected with chlorine at a dosage of 40 mg/L. If the well casing diameter is 6 inches and the length of the water-filled casing is 140 ft, how may lb of chlorine will be required?

17. A new well with a casing diameter of 12 inches is to be disinfected. The desired chlorine dosage is 40 mg/L. If the casing is 190 ft long and the water level in the well is 81 feet from the top of the well, how many lb of chlorine will be required?

18. An existing well has a total casing length of 210 ft. The casing has a 12-inch-diameter at the top 180 ft and an 8-inch diameter at the bottom 40 ft. The water level is 71 feet from the top of the well. How many lb of chlorine will be required if a chlorine dosage of 110 mg/L is desired?

19. The water-filled casing of a well has a volume of 540 gallons. If 0.48 lb of chlorine were used in disinfection, what was the chlorine dosage in mg/L?

20. A total of 0.09 lb of chlorine is required for the disinfection of a well. If sodium hypochlorite (5.25% available chlorine) is to be used, how many fluid ounces of sodium hypochlorite are required?

21. A new well is to be disinfected with calcium hypochlorite (65% available chlorine). The well casing diameter is 6 inches and the length of the water-filled casing is 120 ft. If the desired chlorine dosage is 50 grams per liter (g/L), how many ounces (dry measure) of calcium hypochlorite will be required?

22. How many lb of chloride of lime (25% available chlorine) will be required to disinfect a well if the casing is 18 inches in diameter and 200 ft long with the water level 95 ft from the top of the well? The desired chlorine dosage is 100 mg/L.

23. The water-filled casing of a well has a volume of 240 gallons. How many fluid ounces of sodium hypochlorite (5.25% available chlorine) are required to disinfect the well if a chlorine concentration of 60 mg/L is desired?

## Deep-Well Turbine Pump Calculations

24. The pressure gauge reading at a pump discharge head is 4.0 psi. What is this discharge head expressed in feet?

25. The static water level of a well is 94 ft. The well drawdown is 24 ft. If the gauge reading at the pump discharge head is 3.6 lb per square inch (psi), what is the field head?

26. The pumping water level for a well is 190 ft. The discharge pressure measured at the pump discharge head is 4.2 lb per square inch (psi). If the pump capacity is 800 gpm, what is the water horsepower?

27. The pumping water level for a well is 200 ft. The pump discharge head is 4.4 lb per square inch (psi). If the pump capacity is 1100 gpm, what is the water horsepower?

28. The bowl head of a vertical turbine pump is 184 ft and the bowl efficiency is 83%. If the capacity of the vertical turbine pump is 700 gpm, what is the bowl horsepower?

29. A vertical turbine pump has a bowl horsepower of 59.5 bhp. The shaft is 1-1/4 inches in diameter and rotates at a speed of 1450 rpm. If the shaft is 181 feet long, what is the field bhp? Shaft friction loss is 0.67.

30. The field brake horsepower (bhp) for a deep-well turbine pump is 58.3 bhp. The thrust bearing loss is 0.5 hp. If the motor efficiency provided by the manufacturer is 90%, what is the horsepower input to the motor?

31. The total brake horsepower (bhp) for a deep-well turbine pump is 56.4 bhp. If the water horsepower is 45 whp, what is the field efficiency?

32. The total brake horsepower (bhp) for a pump is 55.7 bhp. If the motor is 90% efficient and the water horsepower (whp) is 43.5 whp, what is the overall efficiency of the unit?

## Pond Storage Capacity

33. A pond has an average length of 400 ft, an average width of 110 ft, and an estimated average depth of 14 ft. What is the estimated volume of the pond (in gallons)?

34. A pond has an average length of 400 ft and an average width of 110 ft. If the maximum depth of the pond is 30 ft, what is estimated gallon volume of the pond?

35. A pond has an average length of 200 ft, an average width of 80 ft, and an average depth of 12 ft. What is the acre-feet volume of the pond?

36. A small pond has an average length of 320 ft, an average width of 170 ft, and a maximum depth of 16 ft. What is the acre-feet volume of the pond?

## Copper Sulfate Dosing

37. For algae control in a reservoir, a dosage of 0.5-milligram per liter (mg/L) copper is desired. The reservoir has a volume of 20 million gallons (MG). How many lb of copper sulfate pentahydrate (25% available copper) will be required?

38. The desired copper dosage in a reservoir is 0.5 mg/L. The reservoir has a volume of 62 acre-feet. How many lb of copper sulfate pentahydrate (25% available copper) will be required?

39. A pond has a volume of 38 acre-feet. If the desired copper sulfate dosage is 1.1 lb $CuSO_4$ per acre-foot, how many lb of copper sulfate will be required?

40. A pond has an average length of 250 ft, an average width of 75 ft, and an average depth of 10 ft. If the desired dosage is 0.8 lb copper sulfate per acre-foot, how many lb of copper sulfate will be required?

41. A storage reservoir has an average length of 500 and an average width of 100 ft. If the desired copper sulfate dosage is 5.1 lb $CuSO_4$ per acre foot, how many lb of copper sulfate will be required?

## General Water Source and Storage Calculations

42. The static water level for a well is 93.5 ft. If the pumping water level is 131.5 ft, what is the drawdown?

43. During a 5-minute well yield test, a total of 707 gallons was pumped from the well. What is the well yield in gallons per minute? In gallons per hour?

44. A bailer is used to determine the approximate yield of a well. The bailer is 12 ft long and has a diameter of 12 inches. If the bailer is placed in the well and removed a total of 8 times during a 5-minute test, what is the well yield (in gpm)?

45. The static water level in a well is 141 feet. The pumping water level is determined using a sounding line. The air pressure applied to the sounding line is 3.5 lb per square inch (psi) and the length of the sounding line is 167 ft. What is the drawdown?

46. A well produces 610 gpm. If the drawdown for the well is 28 ft, what is the specific yield in gallons per minute per foot of drawdown?

47. A new well is to be disinfected with a chlorine dose of 55 mg/L. If the well casing diameter is 6 inches and the length of the water-filled casing is 150 ft, how many lb of chlorine will be required?

48. During a 5-minute well yield test, a total of 780 gallons of water was pumped from the well. At this yield, if the pump is operated a total of 8 hours each day, how many gallons of water are pumped daily?

49. The water-filled casing of a well has a volume of 610 gallons. If 0.47 lb of chlorine was used for disinfection, what was the chlorine dosage (in mg/L)?

50. An existing well has a total casing length of 230 ft. The casing has a 12-inch diameter at the top 170 ft and an 8-inch diameter at the bottom 45 ft. The water level is 81 feet from the top of the well. How many lb of chlorine will be required if a chlorine dosage of 100 mg/L is desired?

51. A total of 0.3 lb of chlorine is required for the disinfection of a well. If sodium hypochlorite is to be used (5.25% available chlorine), how many fluid ounces of sodium hypochlorite are required?

52. The pressure gauge reading at a pump discharge head is 4.5 lb per square inch (psi). What is this discharge head expressed in feet?

53. The static water level of a well is 95 ft. The well drawdown is 25 ft. If the gauge reading at the pump discharge head is 3.6 lb per square inch (psi), what is the field head?

54. The pumping water level for a well is 191 feet. The discharge pressure measured at the pump discharge head is 4.1 lb per square inch (psi). If the pump capacity is 850 gpm, what is the horsepower?

55. A deep-well vertical turbine pump delivers 800 gpm. The bowl head is 175 ft and the bowl efficiency is 80%. What is the bowl horsepower?

56. The field brake horsepower (bhp) for a deep-well turbine pump is 47.8 bhp. The thrust bearing loss is 0.8 hp. If the motor efficiency, as provided by the manufacturer, is 90%, what is the horsepower input to the motor?

57. The total brake horsepower (bhp) for a deep-well turbine is 57.4 bhp. If the water horsepower (whp) is 45.6 whp, what is the field efficiency?

58. The total brake horsepower (bhp) for a pump is 54.7 bhp. If the motor is 90% efficient and the water horsepower (whp) is 44.6 whp, what is the overall efficiency of the unit?

59. The desired copper dosage at a reservoir is 0.5 mg/L. The reservoir has a volume 53 acre-feet. How many lb of copper sulfate pentahydrate (25% available copper) will be required?

60. A storage reservoir has an average length of 440 ft and an average width of 140 ft. If the desired copper sulfate dosage is 5.5 lb copper sulfate per acre, how many lb of copper sulfate will be required?

## Coagulation and Flocculation Calculations: Unit Process Volume

61. A flash mix chamber is 4 ft wide by 5 ft long and contains water to a depth of 3 ft. What is the volume of water in the flash mix chamber (in gallons)?

62. A flocculation basin is 50 ft long by 20 ft wide and contains water to a depth of 8 ft. What is the volume of water in the basin (in gallons)?

63. A flocculation basin is 40 ft long by 16 ft wide and contains water to a depth of 8 ft. How many gallons of water are in the basin?

64. A flash mix chamber is 5 ft square and contains water to a depth of 42 inches. What is the volume of water in the flash mixing chamber (in gallons)?

65. A flocculation basin is 25 ft wide by 40 ft long and contains water to a depth of 9 ft 2 inches. What is the volume of water in the flocculation basin (in gallons)?

## Detention Time

66. The flow to a flocculation basin is 3,625,000 gpd. If the basin is 60 ft long by 25 ft wide and contains water to a depth of 9 ft, what is the detention time of the flocculation basin (in minutes)?

67. A flocculation basin is 50 ft long by 20 ft wide and has a water level of 8 ft. What is the detention time (in minutes) in the basin if the flow to the basin is 2.8 MGD?

68. A flash mix chamber is 6 ft long, 5 ft wide, and 5 ft deep. It receives a flow of 9 MGD. What is the detention time in the chamber (in seconds)?

69. A flocculation basin is 50 ft long by 20 ft wide and has a water depth of 10 ft. If the flow to the basin is 2,250,000 gpd, what is the detention time (in minutes)?

70. A flash mix chamber is 4 ft square and has a water depth of 42 inches. If the flash mix chamber receives a flow of 3.25 MGD, what is the detention time (in seconds)?

## Calculating Dry Chemical Feeder Setting (lb/d)

71. The desired dry alum dosage, as determined by the jar test, is 10 mg/L. Determine the lb/day setting on a dry alum feeder if the flow is 3,450,000 gpd.

72. Jar tests indicate that the best polymer dose for a water sample is 12 mg/L. If the flow to be treated is 1,660,000 gpd, what should the dry chemical feed setting be (in lb/day)?

73. Determine the desired lb/day setting on a dry alum feeder if jar tests indicate an optimum dose of 10 mg/L and the flow to be treated is 2.66 MGD.

74. The desired dry alum dose is 9 mg/L, as determined by a jar test. If the flow to be treated is 940,000 gpd, how many lb/day dry alum will be required?

75. A flow of 4.10 MGD is to be treated with a dry polymer. If the desired dose is 12 mg/L what should the dry chemical feeder setting be (lb/day)?

## Calculating Solution Feeder Setting (gal/d)

76. Jar tests indicate that the best alum dose for a unit process is 7 mg/L. The flow to be treated is 1.66 MGD. Determine the gpd setting for the alum solution feeder if the liquid alum contains 5.24 lb of alum per gallon of solution.

77. The flow to a plant is 3.43 MGD. Jar testing indicates that the optimum alum dose is 12 mg/L. What should the gpd setting be for the solution feeder if the alum solution is 55% solution?

78. Jar tests indicate that the best alum dose for a unit process is 10 mg/L. The flow to be treated is 4.13 MGD. Determine the gpd setting for the alum solution feeder if the liquid alum contains 5.40 lb of alum per gallon of solution.

79. Jar tests indicate that the best liquid alum dose for a unit process is 11 mg/L. The flow to be treated is 880,000 gpd. Determine the gpd setting for the liquid alum chemical feeder if the liquid alum is a 55% solution.

80. A flow of 1,850,000 gpd is to be treated with alum. Jar tests indicate that the optimum alum dose is 10 mg/L. If the liquid alum contains 640 mg alum per milliliter solution, what should be the gallons per day setting for the alum solution feeder?

## Calculating Solution Feeder Setting (mL/min)

81. The desired solution feed rate was calculated to be 40 gpd. What is this feed rate expressed as milliliters per minute?

82. The desired solution feed rate was calculated to be 34.2 gpd. What is this feed rate expressed as milliliters per minute?

83. The optimum polymer dose has been determined to be 10 mg/L. The flow to be treated is 2,880,000 gpd. If the solution to be used contains 55% active polymer, what should the solution chemical feeder setting be (in milliliters per minute)?

84. The optimum polymer dose for a 2,820,000 gpd flow has been determined to be 6 mg/L. If the polymer solution contains 55% active polymer, what should the solution chemical feeder setting be (in milliliters per minute)? Assume the polymer solution weighs 8.34 lb/gal.

85. Jar tests indicate that the best alum dose for a unit process is 10 mg/L. The liquid alum contains 5.40 alum per gallon of solution. What should the setting be on the solution chemical feeder (in milliliters per minute) when the flow to be treated is 3.45 MGD?

## Percent Strength of Solutions

86. If 140 grams of dry polymer are dissolved in 16 gallons of water, what is the percent strength of the solution? (1 gram = 0.0022 lb)

87. If 22 ounces of dry polymer are added to 24 gallons of water, what is the percent strength (by weight) of the polymer solution?

88. How many gallons of water must be added to 2.1 lb dry alum to make an 0.8% solution?

89. An 11% liquid polymer is to be used in making up a polymer solution. How many lb of liquid polymer should be mixed with water to produce 160 lb of a 0.5% polymer solution?

90. An 8% polymer solution is used to make up a solution. How many gallons of liquid polymer should be added to the water to make up 50 gallons of a 0.2% polymer solution? The liquid polymer has a specific gravity of 1.3. Assume the polymer solution has a specific gravity of 1.0.

91. How many gallons of an 11% liquid polymer should be mixed with water to produce 80 gallons of an 0.8% polymer solution? The density of the polymer liquid is 10.1 lb/gal. Assume the density of the polymer solution is 8.34 lb/gal.

## Mixing Solutions of Different Strength

92. If 32 lb of a 10% strength solution are mixed with 66 lb of a 0.5% strength solution, what is the percent strength of the solution mixture?

93. If 5 gallons of a 15% strength solution are added to 40 gallons of a 0.20% strength solution, what is the percent strength of the solution mixture? Assume the 15% strength solution weighs 11.2 lb/gal and the 0.20% solution weighs 8.34 lb/gal.

94. If 12 gallons of a 12% strength solution are mixed with 50 gallons of a 0.75% strength solution, what is the percent strength of the solution mixture? Assume the 12% solution weighs 10.5 lb/gal and the 0.75% solution weighs 8.40 lb/gal.

### Dry Chemical Feeder Calibration

95. Calculate the actual chemical feed rate (in lb/day) if a container is placed under a chemical feeder and 2.3 lb are collected during a 30-minute period.

96. Calculate the actual chemical feed rate (in lb/day) if a container is placed under a chemical feeder and 42 ounces are collected during a 45-minute period.

97. To calibrate a chemical feeder, a container is first weighed (14 ounces) then placed under the chemical feeder. After 30 minutes, the container is weighed again. If the weight of the bucket with chemical is 2.4 lb, what is the actual chemical feed rate (in lb/day)?

98. A chemical feeder is to be calibrated. The container to be used to collect chemical is placed under the chemical feeder and weighed (0.6 lb). After 30 minutes, the weight of the bucket is found to be 2.8 lb. Based on this test, what is the actual chemical feed rate (in lb/day)?

99. During a 24-hour period, a flow of 1,920,000 gpd water is treated. If 42 lb of polymer were used for coagulation during that 24-hour period, what is the polymer dosage (in mg/L)?

### Solution Chemical Feeder Calibration

100. A calibration test is conducted for a solution chemical feeder. During a 24-hour period the solution feeder delivers 70 gallons of solution. The polymer solution is a 1.6% solution. What is the lb/day solution feed rate? Assume the polymer solution weighs 8.34 lb/gal.

101. A calibration test is conducted for a solution chemical feeder. During a 5-minute test, the pump delivers 590 milliliters (mL) of a 1.2% polymer solution. The specific gravity of the polymer solution is 1.09. What is the polymer dosage rate (in lb/day)?

102. During a 5-minute calibration test for a solution chemical feeder, the solution feeder delivers a total of 725 milliliters (mL). The polymer solution is a 1.2% solution. What is the polymer feed rate (in lb/day)? Assume the polymer solution weighs 8.34 lb/gal.

103. A solution chemical feeder delivers 950 milliliters (mL) of solution during a 5-minute calibration test. The polymer solution is a 1.4% strength solution. What is the polymer dosage rate (in lb/day)? Assume the polymer solution weighs 8.34 lb/gal.

104. If 1730 milliliters (mL) of a 1.9% polymer solution are delivered during a 10-minute calibration test, and the polymer solution has a specific gravity of 1.09, what is the polymer feed rate (in lb/day)?

105. A pumping rate calibration test is conducted for a 5-minute period. The liquid level in the 4-foot-diameter solution tank is measured before and after the test. If the level drops 4 inches during the 5-minute test, what is the gallons per minute pumping rate?

106. During a 15-minute pumping rate calibration test, the liquid level in a 4-foot-diameter solution tank drops 4 inches. What is the pumping rate (in gpm)?

107. The liquid level in a 3-foot-diameter solution tank drops 3 inches during a 10-minute pumping rate calibration test. What is the gallons per minute pumping rate? Assuming a continuous pumping rate, what is the gallons per day pumping rate?

108. During a 15-minute pumping rate calibration test, the solution level in a 3-foot-diameter chemical tank drops 2 inches. Assume the pump operates at that rate for the next 24 hours. If the polymer solution is a 1.3% solution, what is the polymer feed (in lb/day)? Assume the polymer solution weighs 8.34 lb/gal.

109. The level in a 4-foot-diameter chemical tank drops 2 inches during a 30-minute pumping rate calibration test. The polymer solution is a 1.45% solution. If the pump operates at the same rate for 24 hours, what is the polymer feed (in lb/day)?

## Chemical Use Calculations

110. Based on the amount of chemical used each day, what was the average chemical use (in lb/day) for the following week: Monday, 81 lb/day; Tuesday, 73 lb/day; Wednesday, 74 lb/day; Thursday, 66 lb/day; Friday, 79 lb/day; Saturday, 80 lb/day; Sunday, 82 lb/day?

111. The average chemical use at a plant is 90 lb/day. If the chemical inventory in stock is 2200 lb, how many days' supply is this?

112. The chemical inventory in stock is 889 lb. If the average chemical use at a plant is 58 lb/day, how many days' supply is this?

113. The average gallons of polymer solution used each day at a treatment plant is 88 gpd. A chemical feed tank has a diameter of 3 ft and contains solution to a depth of 3 ft 4 inches. How many days' supply are represented by the solution in the tank?

114. Jar tests indicate that the optimum polymer dose for a unit process is 2.8 mg/L. If the flow to be treated is 1.8 MGD, how many lb of dry polymer will be required for a 30-day period?

## General Coagulation and Flocculation

115. A flash mix chamber 4 ft long by 4 ft wide with a 3-foot water depth receives a flow of 6.1 MGD. What is the detention time in the chamber (in seconds)?

116. A flocculation basin is 50 ft long by 20 ft wide and has a water depth of 9 ft. What is the volume of water in the basin (in gallons)?

117. The desired dry alum dosage, as determined by jar testing, is 9 mg/L. Determine the lb/day setting on a dry alum feeder if the flow is 4.35 MGD.

118. The flow to a plant is 3.15 MGD. Jar testing indicates that the best alum dose is 10 mg/L. What should the gpd setting be for the solution feeder if the alum solution is a 50% solution? Assume the alum solution weighs 8.34 lb/gal.

119. A flash mix chamber is 4 ft square with a water depth of 2 ft. What is the gallon volume of water in this chamber?

120. A desired solution feed rate was calculated to be 45 gpd. What is this feed rate expressed as milliliters per minute?

121. A flocculation basin is 40 ft long by 20 ft wide and has a water depth of 9 ft 2 inches. If the flow to the basin is 2,220,000 gpd, what is the detention time (in minutes)?

122. The optimum polymer dose has been determined to be 8 mg/L. The flow to be treated is 1,840,000 gpd. If the solution to be used contains 60% active polymer, what should the solution chemical feeder setting be (in milliliters per minute)? The polymer solution weighs 10.2 lb/gal.

123. A desired solution feed rate was calculated to be 80 gpd. What is this feed rate expressed as milliliters per minute?

124. Determine the desired lb/day setting on a dry alum feeder if jar tests indicate an optimum dose of 6 mg/L and the flow to be treated is 925,000 gpd.

125. How many gallons of water must be added to 2.7 lb of dry alum to make a 1.4% solution?

126. If 25 lb of a 16% strength solution are mixed with 140 lb of a 0.6% strength solution, what is the percent strength of the solution mixture?

127. Calculate the chemical feed rate (in lb/day) if a container is placed under a chemical feeder and a total of 4.0 lb of chemical is collected during a 30-minute period.

128. A chemical feeder is to be calibrated. The container to be used to collect chemical is placed under the chemical feeder and weighed (2.0 lb). After 30 minutes, the weight of the container and chemical is found to be 4.2 lb. Based on this test, what is the chemical feed rate (in lb/day)?

129. If 190 grams of dry polymer are dissolved in 25 gallons of water, what is the percent strength (by weight) of the solution? (1 gram = 0.0022 lb)

130. During a 5-minute calibration test for a solution chemical feeder, the feeder delivers a total of 760 milliliters (mL). The polymer solution is a 2.0% solution. What is the lb/day polymer feed rate? Assume the polymer solution weighs 8.34 lb/gal.

131. Jar tests indicate that the best alum dose for a unit process is 14 mg/L. The flow to be treated is 4.2 MGD. Determine the gpd setting for the alum solution feeder if the liquid alum contains 5.66 lb of alum per gallon of solution.

132. A 10% liquid polymer is to be used in making up a polymer solution. How many lb of liquid polymer should be mixed with water to produce 210 lb of a 0.8% polymer solution?

133. How many lb of a 60% polymer solution and water should be mixed together to form 175 lb of a 1% solution?

134. During a 10-minute pumping rate calibration test, the liquid level in a 4-foot-diameter solution tank drops 3 inches. What is the pumping rate (in gpm)?

135. How many gallons of a 10% liquid polymer should be mixed with water to produce 80 gallons of a 0.6% polymer solution? The density of the polymer liquid is 10.2 lb/gal. Assume the density of the polymer solution is 8.34 lb/gal.

136. A calibration test is conducted of a solution chemical feeder. During a 5-minute test, the pump delivers 710 mL of a 0.9% polymer solution. The specific gravity of the polymer solution is 1.3. What is the polymer dosage rate (in lb/day)?

137. Jar tests indicate that the best polymer dose for a unit process is 6 mg/L. If the flow to be treated is 3.7 MGD, at this rate how many lb of dry polymer will be required for a 30-day period?

138. The chemical inventory in stock is 550 lb. If the average chemical use at the plant is 80 lb/day, how many days' supply is this?

## Sedimentation — Tank Volume

139. A sedimentation basin is 70 ft long by 30 ft wide. If the water depth is 14 ft, what is the volume of water in the tank (in gallons)?

140. A circular clarifier has a diameter of 80 ft. If the water depth is 12 ft, how many gallons of water are in the tank?

141. A sedimentation tank is 70 ft long by 20 ft wide and has water to a depth of 10 ft. What is the volume of water in the tank (in gallons)?

142. A sedimentation basin is 40 ft long by 25 ft wide. When the basin contains a total of 50,000 gallons, what would be the water depth?

143. A circular clarifier is 75 ft in diameter. If the water depth is 10 ft 5 inches, what is the volume of water in the clarifier (in gallons)?

## Detention Time

144. A rectangular sedimentation basin is 70 ft long by 25 ft wide and has water to a depth of 10 ft. The flow to the basin is 2,220,000 gpd. Calculate the detention time in hours for the sedimentation basin.

145. A circular clarifier has a diameter of 80 ft and an average water depth of 12 ft. If the flow to the clarifier is 2,920,000 gpd, what is the detention time (in hours)?

146. A rectangular sedimentation basin is 60 ft long and 20 ft wide and contains water to a depth of 10 ft. If the flow to the basin is 1,520,000 gpd, what is the detention time (in hours)?

147. A circular clarifier has a diameter of 60 ft and an average water depth of 12 ft. What flow rate (million gallons per day) corresponds to a detention time of 3 hours.

148. A sedimentation basin is 70 ft long and 25 ft wide. The average water depth is 12 ft. If the flow to the basin is 1,740,000 gpd, what is the detention time in the sedimentation basin (in hours)?

## Surface Overflow Rate

149. A rectangular sedimentation basin is 60 ft long and 25 ft wide. When the flow is 510 gpm, what is the surface overflow rate (in gallons per minute per square foot)?

150. A circular clarifier has a diameter of 70 ft. If the flow to the clarifier is 1610 gpm, what is the surface overflow rate (in gallons per minute per square foot)?

151. A rectangular sedimentation basin receives a flow of 540,000 gpd. If the basin is 50 ft long and 20 ft wide, what is the surface overflow rate (in gallons per minute per square foot)?

152. A sedimentation basin is 80 ft long and 25 ft wide. To maintain a surface overflow rate of 0.5 gallons per minute per square foot, what is the maximum flow to the basin (in gallons per day)?

153. A circular clarifier 60 ft in diameter receives a flow of 1,820,000 gpd. What is the surface overflow rate (in gallons per minute per square foot)?

## Mean Flow Velocity

154. A sedimentation basin is 80 ft long by 25 ft wide and operates at a depth of 12 ft. If the flow to the basin is 1,550,000 gpd, what is the mean flow velocity (in feet per minute)?

155. A sedimentation basin is 70 ft long by 30 ft wide and operates at a depth of 12 ft. If the flow to the basin is 1.8 MGD, what is the mean flow velocity (in feet per minute)?

156. A sedimentation basin is 80 ft long by 30 ft wide. The water level is 14 ft. When the flow to the basin is 2.45 MGD, what is the mean flow velocity (in feet per minute)?

157. The flow to a sedimentation basin is 2,880,000 gpd. If the basin is 70 ft long by 40 ft wide and the depth of water in the basin is 10 ft, what is the mean flow velocity (in feet per minute)?

158. A sedimentation basin is 50 ft long by 25 ft wide and receives a flow of 910,000 gpd. The basin operates at a depth of 10 ft. What is the mean flow velocity in the basin (in feet per minute)?

## Weir Loading Rate

159. A circular clarifier receives a flow of 2,520,000 gpd. If the diameter of the weir is 70 ft, what is the weir loading rate (in gpm/ft)?

160. A rectangular sedimentation basin has a total of 170 ft of weir. If the flow to the basin 1,890,000 gpd, what is the weir loading rate (in gpm/ft)?

161. A rectangular sedimentation basin has a total of 120 ft of weir. If the flow over the weir is 1,334,000 gpd, what is the weir loading rate (in gpm/ft)?

162. A circular clarifier receives a flow of 3.7 MGD. If the diameter of the weir is 70 ft, what is the weir loading rate (in gpm/ft)?

163. A rectangular sedimentation basin has a total of 160 ft of weir. If the flow over the weir is 1.9 MGD, what is the weir loading rate (in gpm/ft)?

## Percent Settled Sludge

164. A 100-milliliter (mL) sample of slurry from a solids contact unit is placed in a graduated cylinder and allowed to settle for 10 minutes. The settled sludge at the bottom of the graduated cylinder after 10 minutes is 22 mL. What is the percent settled sludge of the sample?

165. A 100-milliliter (mL) sample of slurry from a solids contact unit is placed in a graduated cylinder. After 10 minutes, a total of 25 mL of sludge has settled to the bottom of the cylinder. What is the percent settled of the sample?

166. A percent settled sludge test is conducted on a 100-milliliter (mL) sample of solids contact unit slurry. After 10 minutes of settling, a total of 15 mL of sludge has settled to the bottom of the cylinder. What is the percent settled sludge of the sample?

167. A 100-milliliter (mL) sample of slurry from a solids contact unit is placed in a graduated cylinder. After 10 minutes, a total of 16 mL of sludge has settled to the bottom of the cylinder. What is the percent settled sludge of the sample?

## Lime Dosage

168. Raw water requires an alum dose of 52 mg/L, as determined by jar testing. If a residual 40 mg/L alkalinity must be present in the water to promote precipitation of the alum added, what is the total alkalinity required (in mg/L)? (1 mg/L alum reacts with 0.45 mg/L alkalinity)

169. Jar tests indicate that a level of 60 mg/L alum is optimum for a particular raw water unit. If a residual 30 mg/L alkalinity must be present to promote complete precipitation of the alum added, what is the total alkalinity required (in mg/L)? (1 mg/L alum reacts with 0.45 mg/L alkalinity)

170. A total of 40 mg/L alkalinity is required to react with alum and ensure proper precipitation. If the raw water has an alkalinity of 26 mg/L as bicarbonate, how may milligrams per liter alkalinity should be added to the water?

171. A total of 40 mg/L alkalinity is required to react with alum and ensure complete precipitation of the alum added. If the raw water has an alkalinity of 28 mg/L as bicarbonate, how many milligrams per liter alkalinity should be added to the water?

172. A total of 15 mg/L alkalinity must be added to raw water. How many milligrams per liter lime will be required to provide this amount of alkalinity? (1 mg/L alum reacts with 0.45 mg/L alkalinity; 1 mg/L alum reacts with 0.45 mg/L lime)

173. It has been calculated that 20 mg/L alkalinity must be added to a raw water unit. How many milligrams per liter lime will be required to provide this amount of alkalinity? (1 mg/L alum reacts with 0.45 mg/L alkalinity; 1 mg/L alum reacts with 0.35 mg/L lime)

174. Given the following data, calculate the required lime dose (in mg/L): *alum dose required per jar tests*, 55 mg/L; *raw water alkalinity*, 35 mg/L; *residual alkalinity required for precipitation*, 30 mg/L; 1 mg/L alum reacts with 0.45 mg/L alkalinity; 1 mg/L alkalinity reacts with 0.35 mg/L lime.

## Lime Dose Required (lb/d)

175. The lime dose for a raw water unit has been calculated to be 13.8 mg/L. If the flow to be treated is 2.7 MGD, how many lb/day dry lime will be required?

176. The lime dose for a solids contact unit has been calculated to be 12.3 mg/L. If the flow to be treated is 2,2400,000 gpd, how many lb/day lime will be required?

177. The flow to a solids contact clarifier is 990,000 gpd. If the lime dose required is determined to be 16.1 mg/L, how many lb/day lime will be required?

178. A solids contact clarification unit receives a flow of 2.2 MGD. Alum is to be used for coagulation purposes. If a lime dose of 15 mg/L will be required, how many lb/day lime is this?

### Lime Dose Required (g/min)

179. A total of 205 lb/day lime will be required to raise the alkalinity of the water passing through a solids-contact clarifier. How many grams per minute lime does this represent? (1 lb = 453.6 gram)

180. A lime dose of 110 lb/day is required for a raw water unit feeding a solids-contact clarifier. How many grams per minute lime does this represent? (1 lb = 453.6 gram)

181. A lime dose of 12 mg/L is required to raise the pH of a particular water. If the flow to be treated is 900,000 gpd, what grams per minute lime dose will be required? (1 lb = 453.6 gram)

182. A lime dose of 14 mg/L is required to raise the alkalinity of a unit process. If the flow to be treated is 2,660,000 gpd, what is the grams per minute lime dose required? (1 lb = 452.6 grams)

### General Sedimentation Calculations

183. A rectangular sedimentation basin is 65 ft long by 30 ft wide and contains water to a depth of 12 ft. If the flow to the basin is 1,550,000 gpd, what is the detention time (in hours)?

184. A sedimentation basin is 70 ft long by 30 ft wide. If the water depth is 14 ft, what is the volume of water in the tank (in gallons)?

185. A sedimentation basin 65 ft long and 25 ft wide operates at a depth of 12 ft. If the flow to the basin is 1,620,000 gpd, what is the mean flow velocity (in feet per minute)?

186. A rectangular sedimentation basin receives a flow of 635,000 gpd. If the basin is 40 ft long by 25 ft wide, what is the surface overflow rate (in gallons per minute per square foot)?

187. A circular clarifier has a diameter of 70 ft. If the water depth is 14 ft, how many gallons of water are in the tank?

188. A rectangular sedimentation basin has a total of 180 ft of weir. If the flow to the basin is 2,220,000 gpd, what is the weir loading rate (in gallons per minute per foot)?

189. A circular clarifier has a diameter of 60 ft and an average water depth of 10 ft. If the flow to the clarifier is 2.56 MGD, what is the detention time (in hours)?

190. A sedimentation basin 55 ft long by 30 ft wide operates at a depth of 12 ft. If the flow to the basin is 1.75 MGD, what is the mean flow velocity (in feet per minute)?

191. A circular clarifier has a diameter of 70 ft. If the flow to the clarifier is 1700 gpm, what is the surface overflow rate (in gallons per minute per square foot)?

192. A circular clarifier receives a flow of 3.15 MGD. If the diameter of the weir is 70 ft, what is the weir loading rate (in gallons per minute per foot)?

193. A circular clarifier has a diameter of 60 ft and an average water depth of 12 ft. What flow rate (million gallons per day) corresponds to a detention time of 2 hours?

194. The flow to a sedimentation basin is 3.25 MGD. If the basin is 80 ft long by 30 ft wide and the depth of water in the basin is 14 ft, what is the mean flow velocity (in feet per minute)?

195. A 100-milliliter (mL) sample of slurry from a solids contact clarification unit is placed in a graduated cylinder and allowed to settle for 10 minutes. The settled sludge at the bottom of the graduated cylinder after 10 minutes is 26 mL. What is the percent settled sludge of the sample?

196. A raw water unit requires an alum dose of 50 mg/L, as determined by jar testing. If a residual 30 mg/L alkalinity must be present in the water to promote complete precipitation of the alum added, what is the total alkalinity required (in mg/L)? (1 mg/L alum reacts with 0.45 mg/L alkalinity)

197. A sedimentation basin is 80 ft long by 30 ft wide. To maintain a surface overflow rate of 0.7 gallons per minute per square foot, what is the maximum flow to the basin (in gallons per day)?

198. The lime dose for a raw water unit has been calculated to be 14.5 mg/L. If the flow to be treated is 2,410,000 gpd, how many lb/day lime will be required?

199. A 100-milliliter (mL) sample of slurry from a solids contact clarification unit is placed in a graduated cylinder. After 10 minutes, a total of 21 mL of sludge has settled to the bottom of the cylinder. What is the percent settled sludge of the sample?

200. A circular clarifier receives a flow of 3.24 MGD. If the diameter of the weir is 80 ft, what is the weir loading rate (in gallons per minute per foot)?

201. A total of 50 mg/L alkalinity is required to react with alum and ensure complete precipitation of the alum added. If the raw water has an alkalinity of 30 mg/L as bicarbonate, how many milligrams per liter alkalinity should be added to the water?

202. Given the following data, calculate the required lime dose (in mg/L): *alum dose required per jar tests*, 50 mg/L; *raw water alkalinity*, 33 mg/L; *residual alkalinity required for precipitation*, 30 mg/L; 1 mg/L alum reacts with 0.45 mg/L alkalinity; 1 mg/L alkalinity reacts with 0.35 mg/L lime.

203. A total of 192 lb/day lime will be required to raise the alkalinity of the water passing through a solids contact clarifier. How many grams per minute lime does this represent? (1 lb = 453.6 grams)

204. A solids contact clarification unit receives a flow of 1.5 MGD. Alum is to be used for coagulation purposes. If a lime dose of 16 mg/L is required, how many lb/day lime is this?

205. A lime dose of 14 mg/L is required to raise the alkalinity of a raw water unit. If the flow to be treated is 2,880,000 gpd, what is the grams per minute lime dose required?

## Filtration — Flow Rate through a Filter

206. During an 80-hour filter run, a total of 14.2 million gallons of water are filtered. What is the average gpm flow rate through the filter during this time?

207. The flow rate through a filter is 2.97 MGD. What is this flow rate expressed as gpm?

208. At an average flow rate through a filter of 3200 gpm, how long a filter run (in hours) would be required to produce 16 million gallons of filtered water?

209. The influent valve to a filter is closed for a 5-minute period. During this time, the water level in the filter drops 12 inches. If the filter is 45 ft long by 22 ft wide, what is the gpm flow rate through the filter?

210. A filter is 40 ft long by 30 ft wide. To verify the flow rate through the filter, the filter influent valve is closed for a 5-minute period and the water drop is measured. If the water level in the filter drops 14 inches during the 5 minutes, what is the gpm flow rate through the filter?

211. The influent valve to a filter is closed for 6 minutes. The water level in the filter drops 18 inches during the 6 minutes. If the filter is 35 ft long by 18 ft wide, what is the gpm flow rate through the filter?

## Filtration Rate (gpm/ft²)

212. A filter 20 ft long by 18 ft wide receives a flow of 1760 gpm. What is the filtration rate (in gallons per minute per square foot)?

213. A filter has a surface area of 32 ft by 18 ft. If the filter receives a flow a 2,150,000 gpd, what is the filtration rate (in gallons per minute per square foot)?

214. A filter 38 ft long by 24 ft wide produces a total of 18.1 million gallons during a 71.6-hour filter run. What is the average filtration rate for this filter run?

215. A filter 33 ft long by 24 ft wide produces a total of 14.2 million gallons during a 71.4-hour filter run. What is the average filtration rate for this filter run?

216. A filter 38 ft long by 22 ft wide receives a flow of 3.550,000 gpd. What is the filtration rate (in gallons per minute per square foot)?

217. A filter is 38 ft long by 18 ft wide. During a test of filter flow rate, the influent valve to the filter is closed for 5 minutes. The water level drops 22 inches during this period. What is the filtration rate for the filter (in gallons per minute per square foot)?

218. A filter is 33 ft long by 24 ft wide. During a test of flow rate, the influent valve to the filter is closed for 6 minutes. The water level drops 21 inches during this period. What is the filtration rate for the filter (in gallons per minute per square foot)?

## Unit Filter Run Volume (UFRV)

219. The total water filtered between backwashes is 2.87 million gallons. If the filter is 20 ft by 18 ft, what is the unit filter run volume (UFRV) (in gal/sq ft)?

220. The total water filtered during a filter run is 4,180,000 gallons. If the filter is 32 ft long by 20 ft wide, what is the unit filter run volume (UFRV) (in gal/sq ft)?

221. A total of 2,980,000 gallons of water is filtered during a particular filter run. If the filter is 24 ft long by 18 ft wide, what is the unit filter run volume (UFRV) (in gal/sq ft)?

222. The average filtration rate for a filter was determined to be 3.4 gallons per minute per square foot. If the filter run time was 3330 minutes, what is the unit filter run volume (UFRV) (in gal/sq ft)?

223. A filter ran 60.5 hours between backwashes. If the average filtration rate during that time was 2.6 gallons per minute per square foot, what is the unit filter run volume (UFRV) (in gal/sq ft)?

## Backwash (gpm/ft$^2$)

224. A filter with a surface area of 380 square feet has a backwash flow rate of 3510 gpm. What is the filter backwash rate (in gallons per minute per square foot)?

225. A filter 18 ft long by 14 ft wide has a backwash flow rate of 3580 gpm. What is the filter backwash rate (in gallons per minute per square foot)?

226. A filter has a backwash rate of 16 gallons per minute per square foot. What is this backwash rate expressed as inches per minute?

227. A filter 30 ft by 18 ft has a backwash flow rate of 3650 gpm. What is the filter backwash rate (in gallons per minute per square foot)?

228. A filter 18 ft long by 14 ft wide has a backwash rate of 3080 gpm. What is this backwash rate expressed as inches per minute rise?

### Volume of Backwash Water Required (gal)

229. A backwash flow rate of 6650 gpm for a total backwashing period of 6 minutes would require how many gallons of water for backwashing?

230. For a backwash flow rate of 9100 gpm and a total backwash time of 7 minutes, how many gallons of water will be required for backwashing?

231. How many gallons of water would be required to provide a backwash flow rate of 4670 gpm for a total of 5 minutes?

232. A backwash flow rate of 6750 gpm for a total of 6 minutes would require how many gallons of water?

### Required Depth of Backwash Water Tank (ft)

233. A total of 59,200 gallons of water will be required to provide a 7-minute backwash of a filter. What depth of water is required in the backwash water tank to provide this backwashing capability? The tank has a diameter of 40 ft.

234. The volume of water required for backwashing has been calculated to be 62,200 gallons. What is the required depth of water in the backwash water tank to provide this amount of water if the diameter of the tank is 52 ft?

235. A total of 42,300 gallons of water will be required for backwashing filter. What depth of water is required in the backwash water tank to provide this much water? The diameter of the tank is 42 ft.

236. A backwash rate of 7150 gpm is desired for a total backwash time of 7 minutes. What depth of water is required in the backwash water tank to provide this much water? The diameter of the tank is 40 ft.

237. A backwash rate of 8860 gpm is desired for a total backwash time of 6 minutes. What depth of water is required in the backwash water tank to provide this backwashing capability? The diameter of the tank is 40 ft.

238. A filter is 42 ft long by 22 ft wide. If the desired backwash rate is 19 gallons per minute per square foot, what backwash pumping rate (gallons per minute) will be required?

239. The desired backwash pumping rate for a filter is 20 gallons per minute per square foot. If the filter is 36 ft long by 26 ft wide, what backwash pumping rate (gallons per minute) will be required?

240. A filter is 22 ft square. If the desired backwash rate is 16 gallons per minute per square foot, what backwash pumping rate (gallons per minute) will be required?

241. The desired backwash pumping rate for a filter is 24 gallons per minute per square foot. If the filter is 26 ft long by 22 ft wide, what backwash pumping rate (gallons per minute) will be required?

## Percent of Product Water Used for Backwashing

242. A total of 17,100,000 gallons of water is filtered during a filter run. If 74,200 gallons of this product water are used for backwashing, what percent of the product water is used for backwashing?

243. A total of 6.10 million gallons of water were filtered during a filter run. If 37,200 gallons of this product water were used for backwashing, what percent of the product water was used for backwashing?

244. A total of 59,400 gallons of product water is used for filter backwashing at the end of a filter run. If 13,100,000 gallons are filtered during the filter run, what percent of the product water is used for backwashing?

245. A total of 11,110,000 gallons of water is filtered during a particular filter run. If 52,350 gallons of product water are used for backwashing, what percent of the product water is used for backwashing?

## Percent Mud Ball Volume

246. A 3625-milliliter (mL) sample of filter media was taken for mud ball evaluation. The volume of water in the graduated cylinder rose from 600 mL to 635 mL when mud balls were placed in the cylinder. What is the percent mud ball volume of the sample?

247. Five samples of filter media were taken for mud ball evaluation. The volume of water in the graduated cylinder rose from 510 milliliters (mL) to 535 mL when mud balls were placed in the cylinder. What is the percent mud ball volume of the sample? The mud ball sampler has a volume of 705 mL.

248. A filter media is tested for the presence of mud balls. The mud ball sampler has a total sample volume of 705 milliliters (mL). Five samples were taken from the filter. When the mud balls were placed in 520 mL of water, the water level rose of to 595 mL. What is the percent mud ball volume of the sample?

249. Five samples of media filter were taken and evaluated for the presence of mud balls. The volume of water in the graduated cylinder rose from 520 milliliters (mL) to 562 mL when the mud balls were placed in the water. What is the percent mud ball volume of the sample? The mud ball sample has a sample volume of 705 mL.

## General Filtration Calculations

250. During an 80-hour filter run, a total of 11.4 million gallons of water is filtered. What is the average gpm flow rate through the filter during this time?

251. A filter is 40 ft long by 25 ft wide. If the filter receives a flow of 3.56 MGD, what is the filtration rate (in gallons per minute per square foot)?

252. The total water filtered between backwashes is 2.88 million gallons. If the filter is 25 ft by 25 ft, what is the unit filter run volume (in gal/sq ft)?

253. At an average flow rate through a filter of 2900 gpm, how long a filter run (in hours) would be required to produce 14.8 million gallons of filtered water?

254. A filter is 38 ft long by 26 ft wide. To verify the flow rate through the filter, the filter influent valve is closed for a period of 5 minutes and the water drop is measured. If the water level in the filter drops 14 inches during the 5-minute period, what is the gpm flow rate through the filter?

255. A total of 3,450,000 gallons of water is filtered during a particular filter run. If the filter is 30 ft long by 25 ft wide, what is the unit filter run volume (in gal/sq ft)?

256. A filter 30 ft long by 20 ft wide produces a total of 13,500,000 gallons during a 73.8-hour filter run. What is the average filtration rate (gallons per minute per square foot) for this filter run?

257. A filter with a surface area of 360 square feet has a backwash flow rate of 3220 gpm. What is the filter backwash rate (in gallons per minute per square foot)?

258. A backwash flow rate of 6350 gpm for a total backwashing period of 6 minutes would require how many gallons of water for backwashing?

259. The influent valve to a filter is closed for a 5-minute period. During this time, the water level in the filter drops 14 inches. If the filter is 30 ft long by 22 ft wide, what is the filtration rate (in gallons per minute per square foot)?

260. A total of 53,200 gallons of water will be required to provide a 6-minute backwash of a filter. What depth of water is required in the backwash water tank to provide this backwashing capability? The tank has a diameter of 45 ft.

261. The average filtration rate for a filter was determined to be 3.3 gallons per minute per square foot. If the filter run time is 3620 minutes, what is the unit filter run volume (in gal/ft$^2$)?

262. A filter is 40 ft long by 25 ft wide. During a test of filter flow rate, the influent valve to the filter is closed for 5 minutes. The water level drops 20 inches during this period. What is the filtration rate for the filter (in gallons per minute per square foot)?

263. A filter 35 ft by 25 ft has a backwash flow rate of 3800 gpm. What is the filter backwash rate (in gallons per minute per square foot)?

264. How many gallons of water would be required to provide a backwash flow rate of 4500 gpm for a total of 7 minutes?

265. The desired backwash pumping rate for a filter is 16 gallons per minute per square foot. If the filter is 30 ft long by 30 ft wide, what backwash pumping rate (gallons per minute) will be required?

266. A filter 25 ft long by 20 ft wide has a backwash rate of 2800 gpm. What is this backwash rate expressed as inches per minute rise?

267. A filter is 30 ft long by 25 ft wide. During a test of flow rate, the influent valve to the filter is closed for 6 minutes. The water level drops 18 inches during this period. What is the filtration rate for the filter (in gallons per minute per square foot)?

268. A filter is 45 ft long by 25 ft wide. If the desired backwash rate is 18 gallons per minute per square foot, what backwash pumping rate (gallons per minute) will be required?

269. A total of 18,200,000 gallons of water is filtered during a filter run. If 71,350 gallons of this product water are used for backwashing, what percent of the product water is used for backwashing?

270. A total of 86,400 gallons of water will be required for backwashing a filter. What depth of water is required in the backwash water tank to provide this much water? The diameter of the tank is 35 ft.

271. A 3480-milliliter (mL) sample of filter media was taken for mud ball evaluation. The volume of water in the graduated cylinder rose from 500 mL to 527 mL when the mud balls were placed in the cylinder. What is the percent mud ball volume of the sample?

272. A total of 51,200 gallons of product water is used for filter backwashing at the end of a filter run. If 13.8 million gallons are filtered during the filter run, what percent of the product water is used for backwashing?

273. Five samples of filter media were taken for mud ball evaluation. The volume of water in the graduated cylinder rose from 500 milliliters (mL) to 571 mL when the mud balls were placed in the cylinder. What is the percent mud ball volume of the sample? The mud ball sampler has a volume of 695 mL.

274. A 20-foot by 25-foot sand filter is set to operate for 36 hours before being backwashed. Backwashing takes 15 minutes and uses 12 gallons per minute per square foot until the water is clear. The water in the backwash storage tank drops 25 ft during backwash. Each filter run produces 3.7 million gallons. (a) What is the filtration rate (in gallons per minute per square foot)? (b) How many gallons of backwash water were used? (c) What was the percentage of product water used for backwashing? (d) If the initial tank water depth was 70 ft, how deep is the water after backwashing? (e) What is the unit filter run volume (UFRV)?

## Chlorination: Chlorine Feed Rate

275. Determine the chlorinator setting (lb/day) required to treat a flow of 3.5 MGD with a chlorine dose of 1.8 mg/L.

276. A flow of 1,340,000 gpd is to receive a chlorine dose of 2.5 milliliters (mL). What should the chlorinator settling be (in lb/day)?

277. A pipeline 12 inches in diameter and 1200 ft long is to be treated with a chlorine dose of 52 mg/L. How many lb of chlorine will this require?

278. A chlorinator setting is 43 lb per 24 hours. If the flow being treated is 3.35 MGD, what is the chlorine dosage expressed as mg/L?

279. A flow totalizer reading at 9 a.m. on Thursday was 18,815,108 gallons and at 9 a.m. on Thursday was 19,222,420 gallons. If the chlorinator setting is 16 lb for this 24-hour period, what is the chlorine dosage (in mg/L)?

## Chlorine Dose, Demand, and Residual

280. The chlorine demand of a water process is 1.6 mg/L. If the desired chlorine residual is 0.5 mg/L, what is the desired chlorine dose (in mg/L)?

281. The chlorine dosage for a water process is 2.9 milliliters (mL). If the chlorine residual after 30 minutes of contact time is found to be 0.7 mg/L, what is the chlorine demand expressed in mg/L?

282. A flow of 3,880,000 gpd is to be disinfected with chlorine. If the chlorine demand is 2.6 mg/L and a chlorine residual of 0.8 mg/L is desired, what should be the chlorinator setting lb/day?

283. A chlorinator setting is increased by 6 lb/day. The chlorine residual before the increased dosage was 0.4 mg/L. After the increased dose, the chlorine residual was 0.8 mg/L. The average flow rate being treated is 1,100,000 gpd. Is the water being chlorinated beyond the breakpoint?

284. A chlorinator setting of 19 lb of chlorine per 24 hours results in a chlorine residual of 0.4 mg/L. The chlorinator setting is increased to 24 lb per 24 hours. The chlorine residual increases to 0.5 mg/L at this new dosage rate. The average flow being treated is 2,100,000 gpd. On the basis of the data, is the water being chlorinated past the breakpoint?

## Dry Hypochlorite Feed Rate

285. A chlorine dose of 48 lb/day is required to treat a particular water unit. If calcium hypochlorite (65% available chlorine) is to be used, how many lb/day of hypochlorite will be required?

286. A chlorine dose of 42 lb/day is required to disinfect a flow of 2,220,000 gpd. If the calcium hypochlorite to be used contains 65% available chlorine, how many lb/day hypochlorite will be required?

287. A water flow of 928,000 gpd requires a chlorine dose of 2.7 mg/L. If calcium hypochlorite (65% available chlorine) is to be used, how many lb/day of hypochlorite are required?

288. A total of 54 lb of hypochlorite (65% available chlorine) is used in a day. If the flow rate treated is 1,512,000 gpd, what is the chlorine dosage (in mg/L)?

289. A flow of 3,21,000 gpd is disinfected with calcium hypochlorite (65% available chlorine). If 49 lb of hypochlorite are used in a 24-hour period, what is the chlorine dosage (in mg/L)?

## Hypochlorite Solution Feed Rate

290. A total of 36 lb/day sodium hypochlorite is required for disinfection of a flow of 1.7 MGD. How many gallons per day sodium hypochlorite is this?

291. A chlorine dose of 2.7 mg/L is required for adequate disinfection of a water unit. If a flow of 810,000 gpd will be treated, how many gallons per day of sodium hypochlorite will be required? The sodium hypochlorite contains 12% available chlorine.

292. Hypochlorite is used to disinfect water pumped from a well. The hypochlorite solution contains 3% available chlorine. A chlorine dose of 2.2 mg/L is required for adequate disinfection throughout the distribution system. If the flow from the well is 245,000 gpd, how much sodium hypochlorite (gallons per day) will be required?

293. Water from a well is disinfected by a hypochlorinator. The flow totalizer indicates that 2,330,000 gallons of water were pumped during a 70-day period. The 3% sodium hypochlorite solution used to treat the well water is pumped from a 3-foot-diameter storage tank. During the 7-day period, the level in the tank dropped 2 ft 10 inches. What is the chlorine dosage (in mg/L)?

294. A hypochlorite solution (4% available chlorine) is used to disinfect a water unit. A chlorine dose of 1.8 mg/L is desired to maintain an adequate chlorine residual. If the flow being treated is 400 gpm, what hypochlorite solution flow (in gallons per day) will be required?

295. A sodium hypochlorite solution (3% available chlorine) is used to disinfect water pumped from a well. A chlorine dose of 2.9 mg/L is required for adequate disinfection. How many gallons per day of sodium hypochlorite will be required if the flow being chlorinated is 955,000 gpd?

### Percent Strength of Solutions

296. A total of 22 lb of calcium hypochlorite (65% available chlorine) is added to 60 gallons of water. What is the percent chlorine (by weight) of the solution?

297. If 320 grams of calcium hypochlorite are dissolved in 7 gallons of water, what is the percent chlorine (by weight) of the solution? (1 gram = 0.0022 lb)

298. How many lb of dry hypochlorite (65% available chlorine) must be added to 65 gallons of water to make a 3% chlorine solution?

299. A 10% liquid hypochlorite is to be used in making up a 2% hypochlorite solution. How many gallons of liquid hypochlorite should be mixed with water to produce 35 gallons of a 2% hypochlorite solution?

300. How many gallons of 13% liquid hypochlorite should be mixed with water to produce 110 gallons of a 1.2% hypochlorite solution?

301. If 6 gallons of a 12% sodium hypochlorite solution are added to 55-gallon drum, how much water should be added to the drum to produce a 2% hypochlorite solution?

## Mixing Hypochlorite Solutions

302. If 50 lb of a hypochlorite solution (11% available chlorine) are mixed with 220 lb of another hypochlorite solution (1% available chlorine), what is the percent chlorine of the solution mixture?

303. If 12 gallons of a 12% hypochlorite solution are mixed with 60 gallons of a 1.5% hypochlorite solution, what is the percent strength of the solution mixture?

304. If 16 gallons of a 12% hypochlorite solution are added to 70 gallons of 1% hypochlorite solution, what is the percent strength of the solution mixture?

305. The average calcium hypochlorite use at a plant is 44 lb/day. If the chemical inventory in stock is 1000 lb, how many days' supply is this?

306. The average daily use of sodium hypochlorite solution at a plant is 80 gpd. A chemical feed tank has a diameter of 4 ft and contains solution to a depth of 3 ft 8 inches. How many days' supply is represented by the solution in the tank?

307. An average of 24 lb of chlorine is used each day at a plant. How many lb of chlorine would be used in one week if the hour meter on the pump registered 150 hours of operation that week?

308. A chlorine cylinder had 91 lb of chlorine at the beginning of a week. The chlorinator setting is 12 lb per 24 hours. If the pump hour meter indicates the pump has operated a total of 111 hours during the week, how many lb chlorine should be in the cylinder at the end of the week?

309. An average of 55 lb of chlorine is used each day at a plant. How many 150-lb chlorine cylinders will be required each month? Assume a 30-day month.

310. The average sodium hypochlorite use at a plant is 52 gpd. If the chemical feed tank is 3 ft in diameter, how many feet should the solution level in the tank drop in 2 days' time?

## General Chlorination Calculations

311. The chlorine demand of a water unit is 1.8 mg/L. If the desired chlorine residual is 0.9 mg/L, what is the desired chlorine dose (in mg/L)?

312. Determine the chlorinator setting (lb/day) needed to treat a flow of 980,000 gpd with a chlorine dose of 2.3 mg/L.

313. A chlorine dose of 60 lb/day is required to treat a water unit. If calcium hypochlorite (65% available chlorine) is to be used, how many lb/day of hypochlorite will be required?

314. A total of 51 lb/day sodium hypochlorite is required for disinfection of a flow of 2.28 MGD. How many gallons per day sodium hypochlorite is this?

315. The chlorine dosage for a water unit is 3.1 mg/L. If the chlorine residual after 30 minutes of contact time is found to be 0.6 mg/L, what is the chlorine demand expressed in mg/L?

316. A total of 30 lb of calcium hypochlorite (65% available chlorine) is added to 66 gallons of water. What is the percent chlorine (by weight) of the solution?

317. What chlorinator setting is required to treat a flow of 1620 gpm with a chlorine dose of 2.8 mg/L?

318. A chlorine dose of 2.8 mg/L is required for adequate disinfection of a water unit. If a flow of 1.33 MGD will be treated, how many gpd of sodium hypochlorite will be required? The sodium hypochlorite contains 12.5% available chlorine.

319. A pipeline 8 inches in diameter and 1600 ft long is to be treated with a chlorine dose of 60 mg/L. How many lb of chlorine will this require?

320. A chlorinator setting of 15 lb of chlorine per 24 hours results in a chlorine residual of 0.5 mg/L. The chlorinator setting is increased to 18 lb per 24 hours. The chlorine residual increases to 0.6 mg/L at this new dosage rate. The average flow being treated is 2,110,000 gpd. On the basis of these data, is the water being chlorinated past the breakpoint?

321. If 70 gallons of a 12% hypochlorite solution are mixed with 250 gallons of a 2% hypochlorite solution, what is the percent strength of the solution mixture?

322. The average calcium hypochlorite use at a plant is 34 lb/day. If the chemical inventory in stock is 310 lb, how many days' supply is this?

323. The flow totalizer reading at 7 a.m. on Wednesday was 43,200,000 gallons and at 7 a.m. on Thursday was 44,115,670 gallons. If the chlorinator setting is 18 lb for this 24-hour period, what is the chlorine dosage (in mg/L)?

324. A chlorine dose of 32 lb/day is required to disinfect a flow of 1,990,000 gpd. If the calcium hypochlorite to be used contains 60% available chlorine, how many lb/day hypochlorite will be required?

325. Water from a well is disinfected by a hypochlorinator. The flow totalizer indicates that 2,666,000 gallons of water were pumped during a 7-day period. The 2% sodium hypochlorite solution used to treat the well water is pumped from a 4-foot-diameter storage tank. During the 7-day period, the level in the tank dropped 3 ft 4 inches. What is the chlorine dosage (in mg/L)?

326. A flow of 3,350,000 gpd is to be disinfected with chlorine. If the chlorine demand is 2.5 mg/L and a chlorine residual of 0.5 mg/L is desired, what should be the chlorinator setting (in lb/day)?

327. If 12 gallons of a 12% hypochlorite solution are mixed with 50 gallons of a 1% hypochlorite solution, what is the percent strength of the solution mixture?

328. A total of 72 lb of hypochlorite (65% available chlorine) is used in a day. If the flow rate treated is 1,885,000 gpd, what is the chlorine dosage (in mg/L)?

329. A hypochlorite solution (3% available chlorine) is used to disinfect a water unit. A chlorine dose of 2.6 mg/L is desired to maintain an adequate chlorine residual. If the flow being treated is 400 gpm, what hypochlorite solution flow will be required (in gallons per day)?

330. The average daily use of sodium hypochlorite at a plant is 92 gpd. The chemical feed tank has a diameter of 3 ft and contains solution to a depth of 4 ft 1 inches. How many days' supply are represented by the solution in the tank?

331. How many lb of dry hypochlorite (65% available chlorine) must be added to 80 gallons of water to make a 2% chlorine solution?

332. An average of 32 lb of chlorine is used each day at a plant. How many lb of chlorine would be used in a week if the hour meter on the pump registers 140 hours of operation that week?

333. An average of 50 lb of chlorine is used each day at a plant. How many 150-lb chlorine cylinders will be required each month? Assume a 30-day month.

## Fluoridation: Concentration Expressions

334. Express 2.6% concentration in terms of milligrams per liter concentration.

335. Convert 6600 mg/L to percent.

336. Express 29% concentration in terms of milligrams per liter.

337. Express a concentration of 22 lb/million gallons as milligrams per liter.

338. Convert 1.6 mg/L to lb/million gallons.

339. Express a concentration of 25 lb/million gallons as milligrams per liter.

## Percent Fluoride Ion in a Compound

340. The atomic weight for hydrogen is 1.008; silicon, 28.06; and fluoride, 19.00. Calculate the percent fluoride ion present in hydrofluosilicic acid ($H_2SiF_6$).

341. The atomic weight for sodium is 22. 997 and for fluoride is 19.00. Calculate the percent fluoride ion present in sodium fluoride (NaF).

## Calculating Dry Feed Rate (lb/d)

342. A fluoride dosage of 1.6 mg/L is desired. The flow to be treated is 989,000 gpd. How many lb/day dry sodium silicofluoride ($Na_2SiF_6$) will be required if the commercial purity of the $Na_2SiF_6$ is 98% and the percent of fluoride ion in the compound is 60.6%? Assume the raw water contains no fluoride.

343. A fluoride dosage of 1.4 mg/L is desired. How many lb/day dry sodium silicofluoride ($Na_2SiF_6$) will be required if the flow to be treated is 1.78 MGD? The commercial purity of the sodium silicofluoride is 98%, and the percent of fluoride ion in $Na_2SiF_6$ is 60.6%. Assume that the water to be treated contains no fluoride.

344. A flow of 2,880,000 gpd is to be treated with sodium silicofluoride ($Na_2SiF_6$). The raw water contains no fluoride. If the desired fluoride concentration in the water is 1.4 mg/L, what should be the chemical feed rate (in lb/day)? The manufacturer's data indicate that each lb of $Na_2SiF_6$ contains 0.8 lb of fluoride ion. Assume the raw water contains no fluoride.

345. A flow of 3.08 MGD is to be treated with sodium fluoride (NaF). The raw water contains no fluoride, and the desired fluoride concentration in the finished water is 1.1 mg/L. What should be the chemical feed rate (in lb/day)? Each lb of NaF contains 0.45 lb of fluoride ion.

346. A flow of 810,000 gpd is to be treated with sodium fluoride (NaF). The raw water contains 0.08 mg/L fluoride, and the desired fluoride level in the finished water is 1.2 mg/L. What should be the chemical feed rate (in lb/day)? NaF contains 0.45 lb of fluoride ion.

## Percent Strength of Solutions

347. If 9 lb of 98% pure sodium fluoride (NaF) are mixed with 55 gallons of water, what is the percent strength of the solution?

348. If 20 lb of 100% pure sodium fluoride (NaF) are dissolved in 80 gallons of water, what is the percent strength of the solution?

349. How many lb of 98% pure sodium fluoride must be added to 220 gallons of water to make a 1.4% solution of sodium fluoride?

350. If 11 lb of 98% pure sodium fluoride are mixed with 60 gallons water, what is the percent strength of the solution?

351. How many lb of 98% pure sodium fluoride must be added to 160 gallons of water to make a 3% solution of sodium fluoride?

352. A flow of 4.23 MGD is to be treated with a 24% solution of hydrofluosilicic acid. The acid has specific gravity 1.2. If the desired fluoride level in the finished water is 1.2 mg/L, what should be the solution feed rate (in gallons per day)? The raw water contains no fluoride. The percent fluoride ion content of $H_2SiF_6$ is 80%.

353. A flow of 3.1-MGD nonfluoridated water is to be treated with a 22% solution of hydrofluosilicic acid ($H_2SiF_6$). The desired fluoride concentration is 1.2 mg/L. What should be the solution feed rate (in gallons per day)? The hydrofluosilicic acid weighs 9.7 lb/gal. The percent fluoride ion content of $H_2SiF_6$ is 80%.

354. A flow of 910,000 gpd is to be treated with a 2.2% solution of sodium fluoride (NaF). If the desired fluoride ion concentration is 1.8 mg/L, what should be the sodium fluoride feed rate (in gallons per day)? Sodium fluoride has a fluoride ion content of 46.10%. The water to be treated contains 0.09 mg/L fluoride ion. Assume the solution density is 8.34 lb/day.

355. A flow of 1,520,000-gpd nonfluoridated water is to be treated with a 2.4% solution of sodium fluoride (NaF). The desired fluoride level in the finished water is 1.6 mg/L. What should be the sodium fluoride solution feed rate (in gallons per day)? Sodium fluoride has a fluoride ion content of 45.25%. Assume the solution density is 8.34 lb/gal.

356. A desired solution feed rate has been determined to be 80 gpd. What is this feed rate expressed as milliliters per minute?

357. A flow of 2.78 MGD is to be treated with a 25% solution of hydrofluosilicic acid ($H_2SiF_6$) (with a fluoride content of 80%). The raw water contains no fluoride, and the desired fluoride concentration is 1.0 mg/L. The hydrofluosilicic acid weighs 9.8 lb/gal. What should be the solution feed rate (in milliliters per minute)?

## Calculating Fluoride Dosage (mg/L)

358. A total of 40 lb/day of 98% pure sodium silicofluoride ($Na_2SiF_6$) was added to a flow of 1,520,000 gpd. The percent fluoride ion content of $Na_2SiF_6$ is 61%. What was the concentration of fluoride ion in the treated water?

359. A flow of 330,000 gpd is treated with sodium fluoride (NaF) at the rate of 6 lb/day. The commercial purity of the sodium fluoride is 98%, and the fluoride ion content of NaF is 45.25%. Under these conditions, what is the fluoride ion dosage (in mg/L)?

360. A flow of 3.85 MGD nonfluoridated water is treated with a 20% solution of hydrofluosilicic acid ($H_2SiF_6$). If the solution feed rate is 32 gpd, what is the calculated fluoride ion concentration of the treated water? Assume the acid weighs 9.8 lb/gal and the percent fluoride ion in $H_2SiF_6$ is 80%.

361. A flow of 1,920,000-gpd nonfluoridated water is treated with 11% solution of hydrofluosilicic acid ($H_2SiF_6$). If the solution feed rate is 28 gpd, what is the calculated fluoride ion concentration of the finished water? The acid weights 9.10 lb/gal, and the percent fluoride ion in $H_2SiF_6$ is 80%.

362. A flow of 2,730,000-gpd nonfluoridated water is to be treated with a 3% saturated solution of sodium fluoride (NaF). If the solution feed rate is 110 gpd, what is the calculated fluoride ion level in the finished water? Assume the solution weighs 8.34 lb/gal. The percent fluoride ion in NaF is 45.25%.

### Solution Mixtures

363. A tank contains 600 lb of 15% hydrofluosilicic acid ($H_2SiF_6$). If 2600 lb of 25% hydrofluosilicic acid are added to the tank, what is the percent strength of the solution mixture?

364. If 900 lb of 25% hydrofluosilicic acid are added to a tank containing 300 lb of 15% hydrofluosilicic acid, what would be the percent strength of the solution mixture?

365. A tank contains 16% hydrofluosilicic acid ($H_2SiF_6$) contains 400 gallons. If a tanker truck delivers 2200 gallons of 22% hydrofluosilicic acid to be added to the tank, what will be the resulting percent strength of the solution mixture? Assume the 22% solution weighs 9.10 lb/gal and the 16% solution weighs 9.4 lb/gal.

366. A tank contains 325 gallons of an 11% hydrofluosilicic acid. If 1100 gallons of a 20% hydrofluosilicic acid are added to the tank, what is the percent strength of the solution mixture? Assume the 11% acid weighs 9.06 lb/gal and the 20% acid weighs 9.8 lb/gal.

367. A tank contains 220 gallons of a 10% hydrofluosilicic acid with a specific gravity of 1.075. If 1600 gallons of 15% hydrofluosilicic acid are added to the tank, what is the percent strength of the solution mixture? Assume the 15% acid solution weighs 9.5 lb/gal.

## General Fluoridation Calculations

368. Express a 2.9% concentration in terms of milligrams per liter.

369. Calculate the percent fluoride ion present in hydrofluosilicic acid ($H_2SiF_6$). The atomic weights are as follows: hydrogen, 1.008; silicon, 28.06; fluoride, 19.00.

370. Express a concentration of 27 lb per million gallons as milligrams per liter.

371. A fluoride ion dosage of 1.6 mg/L is desired. The nonfluoridated flow to be treated is 2,111,000 gpd. How many lb/day dry 98% pure sodium silicofluoride will be required if the percent fluoride ion in the compound is 61.2%.

372. Calculate the percent fluoride ion present in sodium fluoride (NaF). The atomic weights are as follows: sodium, 22.997; fluoride, 19.00.

373. If 80 lb of 98% pure sodium fluoride (NaF) are mixed with 600 gallons of water, what is the percent strength of the solution?

374. Convert 28,000 mg/L to percent.

375. A desired solution feed rate has been determined to be 80 gpd. What is this feed rate expressed in milliliters per minute?

376. A fluoride dosage of 1.5 mg/L is desired. How many lb/day of 98% pure dry sodium fluoride (NaF) will be required if the flow to be treated is 2.45 MGD? The percent fluoride ion in NaF is 45.25%.

377. How many lb of sodium fluoride (98% pure) must be added to 600 gallons of water to make a 3% solution of sodium fluoride?

378. A flow of 4.11 MGD nonfluoridated water is to be treated with a 21% solution of hydrofluosilicic acid. The acid has a specific gravity of 1.3. If the desired fluoride level in the finished water is 1.4 mg/L, what should be the solution feed rate (in gallons per day)? The percent fluoride ion content of the acid is 80%.

379. If 30 lb of 98% pure sodium fluoride are mixed with 140 gallons water, what is the percent strength of the solution?

380. A flow of 1,880,000 gpd is to be treated with sodium fluoride (NaF) containing 0.44 lb of fluoride ion. The raw water contains 0.09 mg/L and the desired fluoride level in the finished water is 1.4 mg/L. What should be the chemical feed rate (in lb/day)?

381. A flow of 2.8-MGD nonfluoridated water is to be treated with a 20% solution of hydrofluosilicic acid. The desired fluoride concentration is 1.3 mg/L. What should be the solution feed rate (in gallons per day)? The hydrofluosilicic acid weighs 9.8 lb/gal. The percent fluoride ion content of acid is 80%.

382. A tank contains 500 lb of 15% hydrofluosilicic acid. If 1600 lb of 20% hydrofluosilicic acid are added to the tank, what is the percent strength of the solution mixture?

383. A total of 41 lb/day of sodium silicofluoride was added to a flow of 1,110,000 gpd. The commercial purity of the sodium silicofluoride was 98%, and the percent fluoride ion content of the acid was 61%. What was the concentration of fluoride in the treated water?

384. A flow of 1400 gpm nonfluoridated raw water is treated with an 11% solution of hydrofluosilicic acid. If the solution feed rate is 40 gpd, what is the calculated fluoride ion concentration of the finished water? The acid weighs 9.14 lb/gal, and the percent fluoride ion in the acid is 80%.

385. A tank contains 235 gallons of 10% hydrofluosilicic acid. If 600 gallons of a 20% hydrofluosilicic acid are added to the tank, what is the percent strength of the solution mixture? Assume the 10% acid weighs 9.14 lb/gal and the 20% acid weighs 9.8 lb/gal.

386. A flow of 2.88 MGD is to be treated with a 20% solution of hydrofluosilicic acid. The raw water contains no fluoride, and the desired fluoride concentration is 1.1 mg/L. The acid weighs 9.8 lb/gal. What should be the solution feed rate (in milliliters per minute)? The percent fluoride content of acid is 80%.

387. A tank contains 131 gallons of a 9% hydrofluosilicic acid with a specific gravity of 1.115. If 900 gallons of 15% hydrofluosilicic acid are added to the tank, what is the percent strength of the solution mixture? Assume the 15% acid solution weighs 9.4 lb/gal.

388. A flow of 2,910,000 gpd is to be treated with a 5% saturated solution of sodium fluoride (NaF). If the solution feed rate is 120 gpd, what is the calculated fluoride ion level in the finished water? Assume the solution weighs 8.34 lb/gal. The percent fluoride ion in the acid is 45.25%. The raw water contains 0.2 milligram per liter (mg/L) fluoride.

## SOFTENING: EQUIVALENT WEIGHT/HARDNESS OF $CaCO_3$

389. The calcium content of a water sample is 39 mg/L. What is this calcium hardness expressed as $CaCO_3$? The equivalent weight of calcium is 20.04 and the equivalent weight of $CaCO_3$ is 50.045.

390. The magnesium content of a water unit is 33 mg/L. What is this magnesium hardness expressed as $CaCO_3$? The equivalent weight of magnesium is 12.16 and the equivalent weight of $CaCO_3$ is 50.045.

391. A water unit contains 18 mg/L calcium. What is this calcium hardness expressed as $CaCO_3$? The equivalent weight of calcium is 20.04 and for $CaCO_3$ is 50.045.

392. A water unit has a calcium concentration of 75 mg/L as $CaCO_3$ and a magnesium concentration of 91 mg/L as $CaCO_3$. What is the total hardness (as $CaCO_3$) of the sample?

393. Determine the total hardness as $CaCO_3$ of a water unit that has calcium content of 30 mg/L and magnesium content of 10 mg/L. The equivalent weight of calcium is 20.04; magnesium, 12.16; and $CaCO_3$, 50.045.

394. Determine the total hardness as $CaCO_3$ of a water unit that has calcium content of 21 mg/L and magnesium content of 15 mg/L. The equivalent weight of calcium is 20.04; magnesium, 12.16; and $CaCO_3$, 50.045.

## Carbonate and Noncarbonate Hardness

395. A sample of water contains 125 mg/L alkalinity as $CaCO_3$. If the total hardness of the water is 121 mg/L as $CaCO_3$, what is the carbonate and noncarbonate hardness (in mg/L as $CaCO_3$)?

396. The alkalinity of a water unit is 105 mg/L as $CaCO_3$. If the total hardness of the water is 122 mg/L as $CaCO_3$, what is the carbonate and noncarbonate hardness (in mg/L as $CaCO_3$)?

397. A water unit has an alkalinity of 91 mg/L as $CaCO_3$ and a total hardness of 116 mg/L. What is the carbonate and noncarbonate hardness of the water?

398. A water sample contains 112 mg/L alkalinity as $CaCO_3$ and 99 mg/L total hardness as $CaCO_{3.}$ What is the carbonate and noncarbonate hardness of this water?

399. The alkalinity of a water unit is 103 mg/L as $CaCO_3$. If the total hardness of the water is 121 mg/L as $CaCO_3$, what is the carbonate and noncarbonate hardness (in mg/L as $CaCO_3$)?

## Phenolphthalein and Total Alkalinity

400. A 100-milliliter (mL) water sample is tested for phenolphthalein alkalinity. If 2 mL titrant is used to pH 8.3 and the sulfuric acid solution has a normality of 0.02 *N*, what is the phenolphthalein alkalinity of the water (in mg/L as $CaCO_3$)?

401. A 100-milliliter (mL) water sample is tested for phenolphthalein alkalinity. If 1.40 mL titrant is used to pH 8.3 and the normality of the sulfuric acid solution is 0.02 *N*, what is the phenolphthalein alkalinity of the water (in mg/L as $CaCO_3$)?

402. A 100-milliliter (mL) sample of water is tested for alkalinity. The normality of the sulfuric acid used for titrating of 0.02 *N*. If 0.3 mL titrant is used to pH 8.3, and 6.7 mL titrant is used to pH 4.4, what is the phenolphthalein and total alkalinity of the sample?

403. A 100-milliliter (mL) sample of water is tested for phenolphthalein and total alkalinity. A total of 0 mL titrant is used to pH 8.3 and 6.9 mL titrant is used to titrate to pH 4.4. The normality of the acid used for titrating is 0.02 *N*. What are the phenolphthalein and total alkalinity of the sample (in mg/L as $CaCO_3$)?

404. A 100-milliliter (mL) sample of water is tested for alkalinity. The normality of the sulfuric acid used for titrating is 0.02 *N*. If 0.5 mL titrant is used to pH 8.3 and 5.7 mL titrant to pH 4.6, what are the phenolphthalein and total alkalinity of the sample?

## Bicarbonate, Carbonate, and Hydroxide Alkalinity

**ALKALINITY (MG/L AS $CACO_3$)**

| Results of Titration | Bicarbonate Alkalinity | Carbonate Alkalinity | Hydroxide Alkalinity |
|---|---|---|---|
| P = O | T | 0 | 0 |
| P is less than 1/2 T | T – 2P | 2P | 0 |
| P = 1/2 T | 0 | 2P | 0 |
| P is greater than 1/2 T | 0 | 2T – 2P | 2P – 2T |
| P = T | 0 | 0 | T |

*Note:* P = Phenolphthalein alkalinity; T = total alkalinity.

405. A water sample is tested for phenolphthalein and total alkalinity. If the phenolphthalein alkalinity is 8 mg/L as $CaCO_3$ and the total alkalinity is 51 mg/L as $CaCO_3$, what are the bicarbonate, carbonate, and hydroxide alkalinities of the water?

406. A water sample is found to have a phenolphthalein alkalinity of 0 mg/L and a total alkalinity of 67 mg/L. What are the bicarbonate, carbonate, and hydroxide alkalinities of the water?

407. The phenolphthalein alkalinity of a water sample is 12 mg/L as $CaCO_3$, and the total alkalinity is 23 mg/L as $CaCO_3$. What are the bicarbonate, carbonate, and hydroxide alkalinities of the water?

408. Alkalinity titrations on a 100-milliliter (mL) water sample gave the following results: 1.3 mL titrant used to pH 8.3, and 5.3 mL total titrant used to pH 4.6. The normality of the sulfuric acid was 0.02 *N*. What are the phenolphthalein, total, bicarbonate, carbonate, and hydroxide alkalinities of the water?

409. Alkalinity titrations on a 100-mL water sample gave the following results: 1.5 mL titrant used to pH 8.3, and 2.9 mL total titrant used to pH 4.5. The normality of the sulfuric acid was 0.02 *N*. What are the phenolphthalein, total, bicarbonate, carbonate, and hydroxide alkalinities of the water?

## Lime Dosage for Softening

410. Assuming 15% excess lime, a water sample has a carbon dioxide content of 8 mg/L as $CO_2$, total alkalinity of 130 mg/L as $CaCO_3$, and a magnesium content of 22 mg/L as $Mg^{2+}$. Approximately how much quicklime (CaO; 90% purity) will be required for softening?

411. Assuming 15% excess lime, the characteristics of a water unit are as follows: 5 mg/L $CO_2$, total alkalinity of 164 mg/L as $CaCO_3$, and 17 mg/L magnesium as $Mg^{2+}$. What is the estimated hydrated lime ($Ca(OH)_2$; 90% pure) dosage required for softening (in mg/L)?

412. Assuming 15% excess lime, a water sample has the following characteristics: 6 mg/L $CO_2$, total alkalinity of 110 mg/L as $CaCO_3$, and 12 mg/L magnesium as $Mg^{2+}$. What is the estimated hydrated lime ($Ca(OH)_2$; 90% purity) dosage required for softening (in mg/L)?

413. A water sample has a carbon dioxide content of 9 mg/L as $CO_2$, total alkalinity of 180 mg/L as $CaCO_3$, and a magnesium content of 18 mg/L as $MG^{2+}$. Approximately how much quicklime (CaO; 90% purity) will be required for softening?

## Soda Ash Dosage

414. A water unit has a total hardness of 260 mg/L as $CaCO_3$ and a total alkalinity of 169 mg/L. What soda ash dosage (in mg/L) is required to remove the noncarbonate hardness?

415. The alkalinity of a water unit is 111 mg/L as $CaCO_3$ and the total hardness is 240 mg/L as $CaCO_3$. What soda ash dosage (in mg/L) is required to remove the noncarbonate hardness?

416. A water sample has a total hardness of 264 mg/L as $CaCO_3$ and a total alkalinity of 170 mg/L. What soda ash dosage (in mg/L) is required to remove the noncarbonate hardness?

417. Calculate the soda ash required (in mg/L) to soften a water unit if the water has a total hardness of 228 mg/L and a total alkalinity of 108 mg/L.

## Carbon Dioxide for Recarbonation

418. The *A*, *B*, *C*, and *D* factors of the excess lime equation have been calculated as follows: *A* = 8 mg/L; *B* = 130 mg/L; *C* = 0 ; *D* = 66 mg/L. If the residual magnesium is 4 mg/L, what is the carbon dioxide dosage required for recarbonation (in mg/L)?

419. The *A*, *B*, *C*, and *D* factors of the excess lime equation have been calculated as: *A* = 8 mg/L; *B* = 90 mg/L; *C* = 7; *D* = 108 mg/L. If the residual magnesium is 3 mg/L, what carbon dioxide dosage would be required for recarbonation?

420. The $A$, $B$, $C$, and $D$ factors of the excess lime equation were determined to be as follows: $A$ = 7 mg/L; $B$ = 109 mg/L; $C$ = 3; $D$ = 52 mg/L. The magnesium residual is 5 mg/L. What is the carbon dioxide dosage required for recarbonation?

421. The $A$, $B$, $C$, and $D$ factors of the excess lime equation were determined to be as follows: $A$ = 6 mg/L; $B$ = 112 mg/L; $C$ = 6; $D$ = 45 mg/L. If the residual magnesium is 4 mg/L, what carbon dioxide dosage would be required for recarbonation?

## Chemical Feeder Settings

422. Jar tests indicated that the optimum lime dosage is 200 mg/L. If the flow to be treated is 2.47 MGD, what should be the chemical feeder setting (in lb/day)?

423. The optimum lime dosage for a water unit has been determined to be 180 mg/L. If the flow to be treated is 3,120,000 gpd, what should be the chemical feeder setting (in lb/day and lb per minute)?

424. A soda ash dosage of 60 mg/L is required to remove noncarbonate hardness. What should be the lb per hour chemical feeder setting if the flow rate to be treated is 4.20 MGD?

425. What should the chemical feeder setting be (in lb/day and lb per minute) if the optimum lime dosage has been determined to be 130 mg/L and the flow to be treated is 1,850,000 gpd?

426. A total of 40 mg/L soda ash is required to remove noncarbonate hardness from a water process. What should be the chemical feeder setting (in lb per hour and lb per minute) if the flow to be treated is 3,110,000 gpd?

427. The total hardness of a water unit is 211 mg/L. What is this hardness expressed as grains per gallon (gpg)?

428. The total hardness of a water is 12.3 mg/L. What is this concentration expressed as mg/L?

429. The total hardness of a water unit is reported as 240 mg/L. What is the hardness expressed as grains per gallon (gpg)?

430. A hardness of 14 grains per gallon (gpg) is equivalent to how many mg/L?

## Ion Exchange Capacity

431. The hardness removal capacity of an ion exchange resin is 25,000 grains per cubic foot. If the softener contains a total of 105 cubic feet of resin, what is the exchange capacity of the softener (in grains)?

432. An ion exchange water softener has a diameter of 6 ft. The depth of resin is 4.2 ft. If the resin has a removal capacity of 25 kilograins per cubic foot, what is the exchange capacity of the softener (in grains)?

433. The hardness removal capacity of an exchange resin is 20 kilograins per cubic foot. If the softener contains a total of 260 cubic feet of resin, what is the exchange capacity of the softener (in grains)?

434. An ion exchange water softener has a diameter of 8 ft. The depth of resin is 5 ft. If the resin has a removal capacity of 22 kilograins per cubic foot, what is the exchange capacity of the softener (in grains)?

## Water Treatment Capacity

435. An ion exchange softener has an exchange capacity of 2,210,000 grains. If the hardness of the water to be treated is 18.1 grains per gallon (gpg), how many gallons of water can be treated before regeneration of the resin is required?

436. The exchange capacity of an ion exchange softener is 4,240,000 grains. If the hardness of the water to be treated is 16.0 grains per gallon (gpg), how many gallons of water can be treated before regeneration of the resin is required?

437. An ion exchange softener has an exchange capacity of 3,650,000 grains. If the hardness of the water is 270 mg/L, how many gallons of water can be treated before regeneration of the resin is required?

438. The hardness removal capacity of an ion exchange resin is 21 kilograins per cubic foot. The softener contains a total of 165 cubic feet of resin. If the water to be treated contains 14.6 grains per gallon (gpg) hardness, how many gallons of water can be treated before regeneration of the resin is required?

439. The hardness removal capacity of an ion exchange resin is 22,000 grains per cubic feet. The softener has a diameter of 3 ft and a depth of resin of 2.6 ft. If the water to be treated contains 12.8 grains per gallon (gpg) hardness, how many gallons of water can be treated before regeneration of the resin is required?

## Operating Time

440. An ion exchange softener can treat a total of 575,000 gallons of water before regeneration is required. If the flow rate treated is 25,200 gallons per hour (gph), what are the hours of operation before regeneration is required?

441. An ion exchange softener can treat a total of 766,000 gallons of water before regeneration of the resin is required. If the water is to be treated at a rate of 26,000 gallons per hour (gph), what are the hours of operation before regeneration is required?

442. A total of 348,000 gallons of water can be treated by an ion exchange water softener before regeneration of the resin is required. If the flow rate to be treated is 230 gpm, what is the operating time (in hours) until regeneration of the resin will be required?

443. The exchange capacity of an ion exchange softener is 3,120,000 grains. The water to be treated contains 14 grains per gallon (gpg) total hardness. If the flow rate to be treated is 200 gpm, what are the hours of operation before regeneration of the resin is required?

444. The exchange capacity of an ion exchange softener is 3,820,000 grains. The water to be treated contains 11.6 grains per gallon (gpg) total hardness. If the flow rate to be treated is 290,000 gpd, what are the hours of operation before regeneration of the resin is required?

## Salt and Brine Required

445. An ion exchange softener will remove 2,410,000 grains hardness from the water until the resin must be regenerated. If 0.5 lb salt is required for each kilograin removed, how may lb of salt will be required for preparing the brine to be used in resin regeneration?

446. A total of 1,410,000 grains hardness is removed by an ion exchange softener before the resin must be regenerated. If 0.4 lb salt is required for each kilograin removed, how many lb of salt will be required for preparing the brine to be used in resin regeneration?

**SALT SOLUTIONS**

| NaCl (%) | Pounds NaCl per Gallon | Pounds NaCl per Cubic Foot |
|---|---|---|
| 10 | 0.874 | 6.69 |
| 11 | 0.990 | 7.41 |
| 12 | 1.09 | 8.14 |
| 13 | 1.19 | 8.83 |
| 14 | 1.29 | 9.63 |
| 15 | 1.39 | 10.4 |

447. If 410 lb salt are required to make up a brine solution for regeneration and the brine solution is to be a 13% solution of salt, how many gallons of brine will be required for regeneration of the softener? (Use the salt solutions table above to determine the lb salt per gallon brine for a 13% solution.)

448. A total of 420 lb salt will be required to regenerate an ion exchange softener. If the brine solution is to be a 14% brine solution, how many gallons brine will be required? (Use the salt solutions table above to determine the lb salt per gallon brine for a 14% brine solution.)

449. An ion exchange softener removes 1,420,000 grains hardness from the water before the resin must be regenerated and 0.5 lb salt is required for each kilograin hardness removed. If the brine solution is to be a 12% brine solution, how many gallons of brine will be required for regeneration of the softener? (Use the salt solutions table above to determine the lb salt per gallon brine for a 12% brine solution.)

## General Softening Calculations

450. The calcium content of a water sample is 44 mg/L. What is this calcium hardness expressed as $CaCO_3$? The equivalent weight of calcium is 20.04, and the equivalent weight of $CaCO_3$ is 50.045.

451. A 100-milliliter (mL) sample of water is tested for phenolphthalein alkalinity. If 1.8 mL titrant is used to pH 8.3 and the normality of the sulfuric acid solution is 0.02 *N*, what is the phenolphthalein alkalinity of the water (in mg/L as $CaCO_3$)?

452. The magnesium content of a water sample is 31 mg/L. What is this magnesium hardness expressed as $CaCO_3$? The equivalent weight of magnesium is 12.16, and the equivalent weight of $CaCO_3$ is 50.045.

453. How many milliequivalents (meq) of calcium are equal to 24 milligrams (mg) of magnesium?

454. The characteristics of a water unit are as follows: 8 mg/L $CO_2$, 118 mg/L total alkalinity as $CaCO_3$, and 12 mg/L magnesium as $Mg^{2+}$. What is the estimated hydrated lime ($Ca(OH)_2$; 90% pure) dosage required for softening (in mg/L)?

455. Determine the total hardness of $CaCO_3$ of a water unit that has calcium content of 31 mg/L and magnesium content of 11 mg/L. The equivalent weight of calcium is 20.04; magnesium, 12.16; and $CaCO_3$, 50.045.

456. A sample of water contains 112 mg/L alkalinity as $CaCO_3$ and 101 mg/L total hardness of $CaCO_3$. What is the carbonate and noncarbonate hardness of this water?

457. A water sample has a carbon dioxide content of 5 mg/L as $CO_2$, total alkalinity of 156 mg/L as $CaCO_3$, and magnesium content of 11 mg/L as $MG^{2+}$. Approximately how much quicklime (CaO; 90% purity) will be required for softening? (Assume 15% excess lime.)

## WASTEWATER TREATMENT CALCULATIONS (PROBLEMS 1 TO 574)

### Wastewater Collection and Preliminary Treatment

1. An empty screenings hopper 4.3 ft by 5.8 ft is filled to an even depth of 28 inches over the course of 96 hours. If the average plant flow rate was 4.9 MGD during this period, how many cubic feet of screenings were removed per million gallons of wastewater received?

2. A grit channel has a water depth of 1.4 ft and width of 1.7 ft. The flow rate through the channel is 700 gpm. What is the velocity through the channel (in feet per second)?

3. A grit channel has a water depth of 16 inches and a width of 18 inches. The flow rate through the channel is 1.2 MGD. What is the velocity through the channel (in feet per second)?

4. What is the gallon capacity of a wet well 12 ft long, 10 ft wide, and 6 ft deep?

5. A wet well is 14 ft long by 12 ft wide and contains water to a depth of 6 ft. How many gallons of water does it contain?

6. What is the cubic feet capacity of a wet well 9 ft by 9 ft with a maximum depth of 6 ft?

7. The maximum capacity of a wet well is 4850 gallons. If the wet well is 12 ft long by 8 ft wide, what is the maximum depth of water in the wet well?

8. A wet well is 10 ft long by 8 ft wide. If the wet well contains water to a depth of 3.1 feet, what is the volume of water in the wet well (in gallons)?

### Wet Well Pumping Rate

9. A wet well is 10 ft by 10 ft. During a 5-minute pumping test with no influent to the well, a pump lowers the water level 1.8 ft. What is the pumping rate (in gpm)?

10. A wet well is 12 ft by 12 ft. During a 3-minute pumping test with no influent inflow, a pump lowers the water level 1.3 ft. What is the pumping rate (in gpm)?

11. The water level in a wet well drops 17 inches during a 3-minute pumping test without influent to the wet well. If the wet well is 9 ft by 7 ft, what is the pumping rate (in gpm)?

12. During a period of no pumping from a wet well, the water level rises 0.9 ft in 1 minute. If the wet well is 9 ft long by 8 ft wide, what is the flow rate of wastewater entering the wet well (in gpm)?

13. A lift station wet well is 12 ft by 14 ft. For 5 minutes the influent valve is closed and the well level drops 2.2 ft. What is the pumping rate (in gpm)?

14. The influent valve to a 12-foot by 14-foot station wet well is closed for 4 minutes. During this time, the well level dropped 1.9 ft. What is the pump discharge (in gpm)?

15. The dimensions of a wet well for a lift station are 10 ft 9 inches by 12 ft 2 inches. The influent valve to the well is closed only long enough for the level to drop 2 ft. The time to accomplish this was 5 minutes and 30 seconds. At what rate (in gpm) is the pump discharging?

16. A lift station wet well is 11.8 ft by 14 ft. The influent flow to this well is 410 gpm. If the well level rises 1 inch in 8 minutes, how many gpm is the pump discharging?

17. A lift station wet well is 140 inches by 148 inches. The influent flow to this well is 430 gpm. If the well level drops 1.5 inches in 5 minutes, how many gallons per minute is the pump discharging?

18. A lift station wet well is 9.8 ft by 14 ft and has an influent rate of 800 gpm. The level in the well drops 8 inches in 15 minutes and two pumps are in operation. If the first pump discharges at a rate of 500 gpm, at what pumping rate is the second pump discharging?

## Screenings Removed

19. A total of 60 gallons of screenings is removed from the wastewater flow during a 24-hour period. What is the screenings removal reported as cubic feet per day?

20. During the course of a week, 282 gallons of screenings were removed from wastewater screens. What was the average screenings removal (in cubic feet per day)?

21. The flow at a treatment plant is 3.33 MGD. If 4.9 cubic feet of screenings are removed during a 24-hour period, what is the screenings removal reported as cubic feet per million gallons?

22. On a particular day a treatment plant receives a flow of 4.9 MGD. If 81 gallons of screenings are removed that day, what is the screenings removal expressed as cubic feet per million gallons?

23. A total of 48 gallons of screenings is removed from a treatment plant during a 24-hour period. If the treatment plant receives a flow of 2,280,000 gpd, what is the screenings removal expressed as cubic feet per million gallons?

### Screenings Pit Capacity

24. A screenings pit has a capacity of 600 cubic feet. If an average of 2.9 cubic feet of screenings is removed daily from the wastewater flow, in how many days will the pit be full?

25. A screenings pit has a capacity of 9 cubic yards available for screenings. If the plant removes an average of 1.6 cubic feet of screenings per day, in how many days will the pit be filled?

26. A plant has been averaging a screenings removal of 2.6 cubic feet per million gallons. If the average daily flow is 2.9 MGD, how many days will it take to fill a screenings pit with an available capacity of 292 cubic feet?

27. Suppose we want to use a screenings pit for 120 days. If the screenings removal rate is 3.5 cubic feet per day, what is the required screenings pit capacity (in cubic feet)?

## Grit Channel Velocity

28. A grit channel is 4 ft wide, with water flowing to a depth of 18 inches. If the flow meter indicates a flow rate of 1820 gpm, what is the velocity of flow through the channel (in feet per second)?

29. A stick in a grit channel travels 26 ft in 32 seconds. What is the estimated velocity in the channel (in feet per second)?

30. The total flow through both channels of a grit channel is 4.3 cubic feet per second. If each channel is 3 ft wide and water is flowing to a depth of 14 inches, what is the velocity of flow through the channel (in feet per second)?

31. A stick placed in a grit channel flows 36 ft in 32 seconds. What is the estimated velocity in the channel (in feet per second)?

32. The depth of water in a grit channel is 16 inches. The channel is 34 inches wide. If the flow meter indicates a flow of 1140 gpm, what is the velocity of flow through the channel (in feet per second)?

## Grit Removal

33. A treatment plant removes 12 cubic feet of grit in a day. If the plant flow is 8 MGD, what is this removal expressed as cubic feet per million gallons?

34. The total daily grit removal for a plant is 260 gallons. If the plant flow is 11.4 MGD, how many cubic feet of grit are removed per million gallons of flow?

35. The average grit removal at a particular treatment plant is 3.1 cubic feet per million gallons. If the monthly average daily flow is 3.8 MGD, how many cubic yards of grit would be removed from the wastewater flow during one 30-day month?

36. The monthly average grit removal is 2.2 cubic feet per million gallons. If the average daily flow for the month is 4,230,000 gpd, how many cubic yards must be available for grit disposal if the disposal pit is to have a 90-day capacity?

37. A grit channel is 2.6 ft wide and has water flowing to a depth of 16 inches. If the velocity through the channel is 1.1 feet per second, what is the flow rate through the channel (in cubic feet per second)?

38. A grit channel 3 ft wide has water flowing at a velocity of 1.4 ft per second. If the depth of the water is 14 inches, what is the flow rate through the channel (in gallons per day)?

39. A grit channel 32 inches wide has water flowing to a depth of 10 inches. If the velocity of the water is 0.90 ft per second, what is the flow rate in the channel (in cubic feet per second)?

## Plant Loadings

40. A suspended solids test was done on a 50-milliliter (mL) sample. The weight of the crucible and filter before the test was 25.6662 grams. After the sample was filtered and dried, the cooled crucible weight was 25.6782 grams. What was the concentration of suspended solids (in mg/L)?

41. A 26.2345-gram crucible was used to filter 26 milliliters (mL) of raw influent sample for a suspended solids test. The dried crucible weighed 26.2410 grams. What was the concentration of suspended solids (in mg/L)?

42. A BOD test was done on a 6-milliliter (mL) sample. The initial dissolved oxygen (DO) of the sample and dilution water was 8.82 mg/L. The DO of the sample after 5 days of incubation was 4.28 mg/L. What was the BOD of the sample?

43. A BOD test was done on a 5-milliliter (mL) sample. The initial dissolved oxygen (DO) of the sample and dilution water was 7.96 mg/L. The DO of the sample after 5 days of incubation was 4.26 mg/L. What was the BOD of the sample?

44. A wastewater treatment plant receives a flow of 3.13 MGD with a total phosphorus concentration of 14.6 mg/L. How many lb/day plant loading?

45. Raw influent BOD is 310 mg/L. If the influent flow rate is 6.15 MGD, at what rate are the lb of BOD entering the plant?

46. A plant has an influent flow rate of 4.85 MGD and a suspended solids concentration of 188 mg/L. How many lb of suspended solids enter daily?

## General Wastewater Collection and Preliminary Treatment Calculations

47. A plant has been averaging a screenings removal of 2.6 cubic feet per million gallons. If the average daily flow is 2,950,000 gpd, how many days will it take to fill a screenings pit that has an available capacity of 270 cubic feet?

48. During 7 days a total of 210 gallons of screenings were removed from the wastewater screens. What was the average screenings removal (in cubic feet per day)?

49. A total of 5.4 cubic feet of screenings are removed from a wastewater flow over a 24-hour period. If the flow at the treatment plant is 2,910,000 gpd, what is the screenings removal reported as cubic feet per million gallons?

50. A screenings pit has a capacity of 12 cubic yards available for screenings. If the plant removes an average of 2.4 cubic feet of screenings per day, in how many days will the pit be filled?

51. A float is placed in a channel. If the float travels 36 ft in 31 seconds, what is the estimated velocity in the channel (in feet per second)?

52. A grit channel 2.6 ft wide has water flowing to a depth of 15 inches. If the velocity of the water is 0.8 ft per second, what is the flow rate in the channel (in cubic feet per second)?

53. The total daily grit removal for a treatment plant is 200 gallons. If the plant flow is 8.8 MGD, how many cubic feet of grit are removed per million gallons of flow?

54. A grit channel is 2.6 ft wide with water flowing to a depth of 15 inches. If the flow velocity through the channel is 1.8 ft per second, what is the gpm flow through the clarifier?

55. The average grit removal at a particular treatment plant is 2.3 cubic feet per million gallons. If the monthly average daily flow is 3,610,000 gpd, how many cubic yards of grit would be expected to be removed from the wastewater flow during a 30-day month?

56. A grit channel 3 ft wide has water flowing to a depth of 10 inches. If the velocity through the channel is 1 ft per second, what is the flow rate through the channel (in cubic feet per second)?

## PRIMARY TREATMENT

### Sedimentation Calculations

57. A circular clarifier has a capacity of 160,000 gallons. If the flow through the clarifier is 1,810,000 gpd, what is the detention time for the clarifier (in hours)?

58. Flow to a sedimentation tank that is 90 ft long, 25 ft wide, and 10 ft deep is 3.25 MGD. What is the detention time in the tank (in hours)?

59. A circular clarifier receives a steady, continuous flow of 4,350,000 gpd. If the clarifier is 90 ft in diameter and 12 ft deep, what is the clarifier detention time (in hours)?

### Primary Treatment

60. The influent flow rate to a primary settling tank is 2.01 MGD. The tank is 84 ft in length by 20 ft wide and has a water depth of 13.1 feet. What is the detention time of the tank (in hours)?

61. A primary settling tank 90 ft long, 20 ft wide, and 14 ft deep receives a flow rate of 1.45 MGD. What is the surface overflow rate (in gpd/sq ft)?

62. A primary sludge sample is tested for total solids. The dish alone weighed 22.20 grams. The sample with the dish weighed 73.86 grams. After drying, the dish with dry solids weighed 23.10 grams. What was the percent total solids (%TS) of the sample?

63. Primary sludge is pumped to a gravity thickener at 390 gpm. The sludge concentration is 0.8%. How many lb of solids are pumped daily?

64. The raw influent suspended solids concentration is 140 mg/L. The primary effluent concentration of suspended solids is 50 mg/L. What percentage of the suspended solids is removed by primary treatment?

65. A primary tank with a total weir length of 80 ft receives a flow rate of 1.42 MGD. What is the weir overflow rate (in gpd/ft)?

66. A wastewater treatment plant has eight primary tanks. Each tank is 80 ft long by 20 ft wide with a side water depth of 12 ft and a total weir length of 86 ft. The flow rate to the plant is 5 MGD. Three tanks are currently in service. Calculate the detention time (in minutes), the surface overflow rate (in gpd/sq ft), and the weir overflow rate (in gpd/ft).

67. The flow to a sedimentation tank that is 80 ft long, 35 ft wide, and 12 ft deep is 3.24 MGD. What is the detention time in the tank (in hours)?

## Weir Overflow Rate

68. A rectangular clarifier has a total of 112 ft of weir. What is the weir overflow rate (in gpd/ft) when the flow is 1,520,000 gpd?

69. A circular clarifier receives a flow of 2.98 MGD. If the diameter of the weir is 70 ft, what is the weir overflow rate (in gpd/ft)?

70. The average flow to a clarifier is 2520 gpm. If the diameter of the weir is 90 ft, what is the weir overflow rate (in gpd/ft)?

71. The total feet of weir for a clarifier is 192 ft. If the flow to the weir is 1.88 MGD, what is the weir overflow rate (in gpd/ft)?

### Surface Overflow Rate

72. A circular clarifier has a diameter of 70 ft. If the primary clarifier influent flow is 2,910,000 gpd, what is the surface overflow rate (in gpd/sq ft)?

73. A sedimentation basin 80 ft by 30 ft receives a flow of 2.35 MGD. What is the surface overflow rate (in gpd/sq ft)?

74. A sedimentation tank is 80 ft long by 30 ft wide. If the flow to the tank is 2,620,000 gpd, what is the surface overflow rate (in gpd/sq ft)?

75. The average flow to a secondary clarifier is 2610 gpm. What is the surface overflow rate (in gpd/sq ft) if the secondary clarifier has a diameter of 60 ft?

### Solids Loading Rate

76. A secondary clarifier is 70 ft in diameter and receives a combined primary effluent and return-activated sludge (RAS) flow of 4.1 MGD. If the mixed liquor suspended solids (MLSS) concentration in the aeration tank is 3110 mg/L, what is the solids loading rate on the secondary clarifier (in lb/day/sq ft)?

77. A secondary clarifier is 80 ft in diameter and receives a primary effluent flow of 3.3 MGD and a return sludge flow of 1.1 MGD. If the mixed liquor suspended solids (MLSS) concentration is 3220 mg/L, what is the solids loading rate on the secondary clarifier (in lb/day per square feet)?

78. The MLSS concentration in an aeration tank is 2710 mg/L. The 70-foot-diameter secondary clarifier receives a combined primary effluent and return-activated sludge (RAS) flow of 3,220,000 gpd. What is the solids loading rate on the secondary clarifier (in lb suspended solids per day per square foot)?

79. A secondary clarifier is 80 ft in diameter and receives a primary effluent flow of 2,320,000 gpd and a return sludge flow of 660,000 gpd. If the MLSS concentration is 3310 mg/L, what is the solids loading rate on the clarifier (in lb/day/sq ft)?

## BOD and SS Removed (lb/d)

80. If 110 mg/L suspended solids are removed by a primary clarifier, how many lb/day suspended solids are removed when the flow is 5,550,000 gpd?

81. The flow to a primary clarifier is 2,920,000 gpd. If the influent to the clarifier has a suspended solids concentration of 240 mg/L and the primary effluent has 200 mg/L suspended solids, how many lb/day suspended solids are removed by the clarifier?

82. The flow to a secondary clarifier is 4.44 MGD. If the influent BOD concentrating is 200 mg/L and the effluent concentration is 110 mg/L, how many lb of BOD are removed daily?

83. The flow to a primary clarifier is 980,000 gpd. If the influent to the clarifier has suspended solids concentration of 320 mg/L and the primary effluent has a suspended solids concentration of 120 mg/L, how many lb/day suspended solids are removed by the clarifier?

## Unit Process Efficiency Calculations

84. The suspended solids entering a primary clarifier is 230 mg/L. If the suspended solids in the primary clarifier effluent is 95 mg/L, what is the suspended solids removal efficiency of the primary clarifier?

85. The concentration of suspended solids entering a primary clarifier is 188 mg/L. If the concentration of suspended solids in the primary clarifier effluent is 77 mg/L, what is the suspended solids removal efficiency of the primary clarifier?

86. The influent to a primary clarifier has a BOD content of 280 mg/L. If the primary clarifier effluent has a BOD concentration of 60 mg/L, what is the BOD removal efficiency of the primary clarifier?

87. The BOD concentration of a primary clarifier is 300 mg/L. If the primary clarifier effluent BOD concentration is 189 mg/L, what is the BOD removal efficiency of the primary clarifier?

## General Sedimentation Calculations

88. The flow to a circular clarifier is 4,120,000 gpd. If the clarifier is 80 ft in diameter and 10 ft deep, what is the clarifier detention time (in hours)?

89. A circular clarifier has a diameter of 60 ft. If the primary clarifier influent flow is 2,320,000 gpd, what is the surface overflow rate (in gpd/sq ft)?

90. A rectangular clarifier has a total of 215 ft of weir. What is the weir overflow rate (in gpd/ft) when the flow is 3,410,000 gpd?

91. A 60-foot-diameter secondary clarifier receives a primary effluent flow of 1,910,000 gpd and a return sludge flow of 550,000 gpd. If the MLSS concentration is 2710 mg/L, what is the solids loading rate on the clarifier (in lb/day/sq ft)?

92. A circular primary clarifier has a diameter of 70 ft. If the influent flow to the clarifier is 3.10 MGD, what is the surface overflow rate (in gpd/sq ft)?

93. A secondary clarifier is 80 ft in diameter and receives a primary effluent flow of 3,150,000 gpd and a return sludge flow of 810,000 gpd. If the mixed liquor suspended solids concentration is 2910 mg/L, what is the solids loading rate in the clarifier (in lb/day/sq ft)?

94. The flow to a secondary clarifier is 5.3 MGD. If the influent BOD concentration is 228 mg/L and the effluent BOD concentration is 110 mg/L, how many lb/day BOD are removed daily?

95. The flow to a sedimentation tank that is 90 ft long, 40 ft wide, and 14 ft deep is 5.10 MGD. What is the detention time in the tank (in hours)?

96. The average flow to a clarifier is 1940 gpm. If the diameter of the wire is 70 ft, what is the weir overflow rate (in gpd/ft)?

97. The flow to a secondary clarifier is 4,440,000 gpd. How many lb of BOD are removed daily if the influent BOD concentration is 190 mg/L and the effluent BOD concentration is 106 mg/L?

98. The flow to a primary clarifier is 3.88 MGD. If the influent to the clarifier has suspended solids concentration of 290 mg/L and the primary clarifier effluent has a suspended solids concentration of 80 mg/L, how may lb/day suspended solids are removed by the clarifier?

99. The primary clarifier influent has a BOD concentration of 260 mg/L. If the primary clarifier effluent has a BOD concentration of 69 mg/L, what is the BOD removal efficiency of the primary clarifier?

100. A sedimentation tank is 90 ft long by 40 ft wide. If the flow to the tank is 2,220,000 gpd, what is the surface overflow rate (in gpd/sq ft)?

## TRICKLING FILTERS

### Hydraulic Loading Rate

101. A trickling filter, 80 ft in diameter, treats a primary effluent flow of 660,000 gpd. If the recirculated flow to the trickling filter is 120,000 gpd, what is the hydraulic loading rate on the trickling filter (in gpd/sq ft)?

102. A high-rate trickling filter receives a flow of 2360 gpm. If the filter has a diameter of 90 ft, what is the hydraulic loading rate on the filter (in gpd/sq ft)?

103. The total influent flow (including recirculation) to a trickling filter is 1.5 MGD. If the trickling filter is 90 ft in diameter, what is the hydraulic loading rate on the trickling filter (in gpd/sq ft)?

104. A high-rate trickling filter receives a daily flow of 2.1 MGD. What is the hydraulic loading rate (in million gallons per day per acre) if the filter is 96 ft in diameter?

## Organic Loading Rate

105. A trickling filter, 100 ft in diameter with a media depth of 6 ft, receives a flow of 1,400,000 gpd. If the BOD concentration of the primary effluent is 210 mg/L, what is the organic loading on the trickling filter (in lb BOD/day/1000 cu ft)?

106. A 90-foot-diameter trickling filter with a media depth of 7 ft receives a primary effluent flow of 3,400,000 gpd with a BOD of 111 mg/L. What is the organic loading on the trickling filter (in lb BOD/day/1000 cu ft)?

107. A trickling filter, 80 ft in diameter with a media depth of 7 ft, receives a flow of 0.9 MGD. If the BOD concentration of the primary effluent is 201 mg/L, what is the organic loading on the trickling filter (in lb BOD/day/1000 cu ft)?

108. A trickling filter has a diameter of 90 ft and a media depth of 5 ft. The primary effluent has a BOD concentration of 120 mg/L. If the total flow to the filter is 1.4 MGD, what is the organic loading (in lb per acre-foot)?

### BOD and SS Removed (lb/d)

109. If 122 mg/L suspended solids are removed by a trickling filter, how many lb/day suspended solids are removed when the flow is 3,240,000 gpd?

110. The flow to a trickling filter is 1.82 MGD. If the primary effluent has a BOD concentration of 250 mg/L and the trickling filter effluent has a BOD concentration of 74 mg/L, how many lb of BOD are removed?

111. If 182 mg/L of BOD are removed from a trickling filter when the flow to the trickling filter is 2,920,000 gpd, how many lb/day BOD are removed?

112. The flow to a trickling filter is 5.4 MGD. If the trickling filter effluent has a BOD concentration of 28 mg/L and the primary effluent has a BOD concentration of 222 mg/L, how many lb of BOD are removed daily?

### Unit Process or Overall Efficiency

113. The suspended solids concentration entering a trickling filter is 149 mg/L. If the suspended solids concentration in the trickling filter effluent is 48 mg/L, what is the suspended solids removal efficiency of the trickling filter?

114. The influent to a primary clarifier has a BOD content of 261 mg/L. The trickling filter effluent BOD is 22 mg/L. What is the BOD removal efficiency of the treatment plant?

115. The concentration of suspended solids entering a trickling filter is 201 mg/L. If the concentration of suspended solids in the trickling filter effluent is 22 mg/L, what is the suspended solids removal efficiency of the trickling filter?

116. The concentration of suspended solids entering a trickling filter is 111 mg/L. If 88 mg/L suspended solids are removed from the trickling filter, what is the suspended solids removal efficiency of the trickling filter?

## Recirculation Ratio

117. A treatment plant receives a flow of 3.4 MGD. If the trickling filter effluent is recirculated at the rate of 3.5 MGD, what is the recirculation ratio?

118. The influent to the trickling filter is 1.64 MGD. If the recirculated flow is 2.32 MGD, what is the recirculation ratio?

119. The trickling filter effluent is recirculated at the rate of 3.86 MGD. If the treatment plant receives a flow of 2.71 MGD, what is the recirculation ratio?

120. A trickling filter has a desired recirculation ratio of 1.6. If the primary effluent flow is 4.6 MGD, what is the desired recirculated flow (in million gallons per day)?

## General Trickling Filter Calculations

121. A trickling filter that is 90 ft in diameter treats a primary effluent flow rate of 0.310 MGD. If the recirculated flow to the clarifier is 0.355 MGD, what is the hydraulic loading rate on the trickling filter (in gpd/sq ft)?

122. A treatment plant receives a flow rate of 2.8 MGD. If the trickling filter effluent is recirculated at a rate of 4.55 MGD, what is the recirculated ratio?

123. A trickling filter 80 ft in diameter with a media depth of 6 ft receives a primary effluent flow rate of 1,350,000 gpd. If the population equivalent BOD is 75 mg/L, what is the organic loading rate on the unit in lb/day per 1000 cubic feet?

124. The flow rate to a trickling filter is 4.1 MGD. If the population equivalent BOD is 81 mg/L and the secondary effluent BOD is 13 mg/L, how many lb of BOD are removed daily?

125. A standard-rate filter, 80 ft in diameter, treats a primary effluent flow of 520,000 gpd. If the recirculated flow to the trickling filter is 110,000 gpd, what is the hydraulic loading rate on the filter (in gpd/sq ft)?

126. A trickling filter, 90 ft in diameter with a media depth of 6 ft, receives a flow of 1,400,000 gpd. If the BOD concentration of the primary effluent is 180 mg/L, what is the organic loading on the trickling filter (in lb BOD/day/1000 cu ft)?

127. If 114 mg/L suspended solids are removed by a trickling filter, how many lb/day suspended solids are removed when the flow is 2,840,000 gpd?

128. The suspended solids concentration entering a trickling filter is 200 mg/L. If the suspended solids concentration in the trickling filter effluent is 69 mg/L, what is the suspended solids removal efficiency of the trickling filter?

129. The flow to a trickling filter is 1.44 MGD. If the primary effluent has a BOD concentration 242 mg/L and the trickling filter effluent has a BOD concentration of 86 mg/L, how many lb of BOD are removed?

130. A high-rate trickling filter receives a combined primary effluent and recirculated flow of 2.88 MGD. If the filter has a diameter of 90 ft, what is the hydraulic loading rate on the filter (in gpd/sq ft)?

131. The influent of a primary clarifier has a BOD content of 210 mg/L. The trickling filter effluent BOD is 22 mg/L. What is the BOD removal efficiency of the treatment plant?

132. An 80-foot-diameter trickling filter with a media depth of 6 ft receives a flow of 2,230,000 gpd. If the BOD concentration of the primary effluent is 141 mg/L, what is the organic loading on the trickling filter (in lb BOD/day/1000 cu ft)?

133. A trickling filter has a diameter of 90 ft and an average media depth of 6 ft. The primary effluent has a BOD concentration of 144 mg/L. If the total flow to the filter is 1.26 MGD, what is the organic loading (in lb/day per acre-feet)?

134. The flow to a trickling filter is 4.22 MGD. If the trickling filter effluent has a BOD concentration of 21 mg/L and the primary effluent has a BOD concentration of 199 mg/L, how many lb of BOD are removed daily?

135. A treatment plant receives a flow of 3.6 MGD. If the trickling filter effluent is recirculated at the rate of 3.8 MGD, what is the recirculation ratio?

136. A high-rate trickling filter receives a daily flow of 1.9 MGD. What is the hydraulic loading rate (in million gallons per day per acre) if the filter is 80 ft in diameter?

137. The total influent flow (including recirculation) to a trickling filter is 1.93 MGD. If the trickling filter is 90 ft in diameter, what is the hydraulic loading on the trickling filter (in gpd/sq ft)?

138. A trickling filter, 70 ft in diameter with a media depth of 6 ft, receives a flow of 0.81 MGD. If the BOD concentration of the primary effluent is 166 mg/L, what is the organic loading on the trickling filter (in lb BOD/day/1000 cu ft)?

139. The influent to the trickling filter is 1.67 MGD. If the recirculated flow is 2.35 MGD, what is the recirculation ratio?

140. The suspended solids concentration entering a trickling filter is 243 mg/L. If the suspended solids concentration of the trickling filter effluent is 35 mg/L, what is the suspended solids removal efficiency of the trickling filter?

## Rotating Biological Contactors (RBCs)

### Hydraulic Loading Rate

141. A rotating biological contactor (RBC) treats a primary effluent flow of 2.98 MGD. If the media surface area is 720,000 square feet, what is the hydraulic loading rate on the RBC (in gpd/sq ft)?

142. A rotating biological contactor (RBC) treats a flow of 4,725,000 gpd. Information provided by the manufacturer indicates that the media surface area is 880,000 square feet. What is the hydraulic loading rate on the RBC (in gpd/sq ft)?

143. Assume a media surface area of 440,000 square feet and that the rotating biological contactor (RBC) treats a flow of 1.55 MGD. What is the hydraulic loading rate on the RBC (in gpd/sq ft)?

144. A rotating biological contactor has a media area of 800,000 square feet. For a maximum hydraulic loading of 7 gpd/sq ft, what is the desired gallons per day flow to the contactor?

## Soluble BOD

145. The suspended solids concentration of a wastewater is 241 mg/L. If the normal *K* value at the plant is 0.55, what is the estimated particulate BOD concentration of the wastewater?

146. The wastewater entering a rotating biological contactor has a BOD content of 222 mg/L. The suspended solids content is 241 mg/L. If the *K* value is 0.5, what is the estimated soluble BOD of the wastewater (in mg/L)?

147. The wastewater entering a rotating biological contactor has a BOD content of 240 mg/L. The suspended solids concentration of the wastewater is 150 mg/L. If the *K* value is 0.5, what is the estimated soluble BOD of the wastewater (in mg/L)?

148. A rotating biological contactor receives a flow of 1.9 MGD with a BOD concentration of 288 mg/L and a suspended solids concentration of 268 mg/L. If the *K* value is 0.6, how many lb/day soluble BOD enter the RBC?

## Organic Loading Rate

149. A rotating biological contactor (RBC) has a media surface area of 980,000 square feet and receives a flow of 4,350,000 gpd. If the soluble BOD concentration of the primary effluent is 160 mg/L, what is the organic loading rate on the RBC (in lb/day per 1000 square feet)?

150. A rotating biological contactor (RBC) has a media surface area of 640,000 square feet and receives a flow of 1,520,000 gpd. If the soluble BOD concentration of the primary effluent is 179 mg/L, what is the organic loading rate on the RBC (in lb/day per 1000 square feet)?

151. The wastewater flow to a rotating biological contactor (RBC) is 2,820,000 gpd. The wastewater has a soluble BOD concentration of 128 mg/L. The RBC media has a total surface area of 660,000 square feet. What is the organic loading rate on the RBC (in lb/day per 1000 square feet)?

152. A rotating biological contactor (RBC) receives a flow of 2.8 MGD. The BOD of the influent wastewater to the RBC is 187 mg/L and the surface area of the media is 765,000 square feet. If the suspended solids concentration of the wastewater is 144 mg/L and the *K* value is 0.52, what is the organic loading rate (in lb/day per 1000 square feet)?

## General RBC Calculations

153. A rotating biological contactor (RBC) unit treats a flow rate of 0.45 MGD. The two shafts used provide a total surface area of 190,000 square feet. What is the hydraulic loading on the unit (in gpd/sq ft)?

154. The influent to a rotating biological contactor (RBC) has a total BOD concentration of 190 mg/L and a suspended solids concentration of 210 mg/L. Assuming 0.6 lb of particulate BOD per lb of suspended solids, estimate the soluble BOD concentration (in mg/L).

155. A rotating biological contactor (RBC) receives a flow rate of 1.9 MGD. If the influent soluble BOD concentration is 128 mg/L and the total media surface area is 410,000 square feet for the RBC unit, what is the organic loading (in lb/day per 1000 square feet)?

156. Estimate the soluble BOD loading on a rotating biological contactor (RBC) treating a flow rate of 0.71 MGD. The total unit surface area is 110,000 square feet. The total BOD concentration is 210 mg/L with a suspended solids concentration of 240 mg/L and a *K* value of 0.65.

157. A rotating biological contactor (RBC) unit contains two shafts operated in series, each with a surface area of 103,000 square feet. The shafts can both be partitioned by baffles at 25%-shaft-length intervals. Currently, the first stage of the RBC unit is baffled to use 75% of one of the two shafts. The unit receives a flow rate of 0.455 MGD. The primary effluent total BOD concentration is 241 mg/L. The suspended solids concentration is 149 mg/L and the value of *K* is 0.5. Calculate the hydraulic loading, unit organic loading, and first-stage organic loading.

158. A rotating biological contactor (RBC) treats a primary effluent flow of 2.96 MGD. If the media surface area is 660,000 square feet, what is the hydraulic loading rate on the RBC (in gpd/sq ft)?

159. The suspended solids concentration of a wastewater is 222 mg/L. If the normal *K* value at the plant is 0.5, what is the estimated particulate BOD concentration of the wastewater?

160. A rotating biological contactor (RBC) has a media surface area of 720,000 square feet and receives a flow of 1,920,000 gpd. If the soluble BOD concentration of the primary effluent is 151 mg/L, what is the organic loading on the RBC (in lb/day per 1000 square feet)?

161. A rotating biological contactor (RBC) receives a flow of 2.9 MGD with a BOD concentration of 205 mg/L and suspended solids of 210 mg/L. If the *K* value is 0.6, how many lb/day soluble BOD enter the RBC?

162. A rotating biological contactor (RBC) treats a flow of 4,475,000 gpd. The manufacturer's data indicate a media surface area of 910,000 square feet. What is the hydraulic loading rate on the RBC (in gpd/sq ft)?

163. The wastewater flow to a rotating biological contactor (RBC) is 2,415,000 gpd. The wastewater has a soluble BOD concentration of 121 mg/L. The RBC media has a surface area of 760,000 square feet. What is the organic loading rate on the RBC (in lb/day per 1000 square feet)?

## Activated Sludge

### Aeration Tank, Secondary Clarifier, and Oxidation Ditch Volume

164. An aeration tank is 80 ft long by 25 ft wide and operates at an average depth of 14 ft. What is the capacity of the tank (in gallons)?

165. What is the gallon capacity of an aeration tank that is 80 ft long by 30 ft wide and operates at an average depth of 12 ft?

166. A secondary clarifier has a diameter of 80 ft and an average depth of 12 ft. What is the volume of water in the clarifier (in gallons)?

167. A clarifier has a diameter of 70 ft and an average depth of 10 ft. What is the volume of water in the clarifier (in gallons)?

### BOD or COD Loading (lb/d)

168. The flow to an aeration tank is 880,000 gpd. If the BOD content of the wastewater entering the aeration tank is 240 mg/L, what is the lb/day BOD loading?

169. The flow to an aeration tank is 2980 gpm. If the COD concentration of the wastewater is 160 mg/L, how many lb of COD are applied to the aeration tank daily?

170. The BOD content of the wastewater entering an aeration tank is 165 mg/L. If the flow to the aeration tank is 3,240,000 gpd, what is the lb/day BOD loading?

171. The daily flow to an aeration tank is 4,880,000 gpd. If the COD concentration of the influent wastewater is 150 mg/L, how many lb of COD are applied to the aeration tank daily?

### Aeration Tank: Solids Inventory

172. If the mixed liquor suspended solids concentration is 2110 mg/L and the aeration tank has a volume of 460,000 gallons, how many lb of suspended solids are in the aeration tank?

173. The aeration tank of a conventional activated sludge plant has a mixed liquor volatile suspended solids (MLVSS) concentration of 2420 mg/L. If the aeration tank is 90 ft long by 50 ft wide and has wastewater to a depth of 16 ft, how many lb of MLVSS are under aeration?

174. The aeration tank of a conventional activated sludge plant has a mixed liquor volatile suspended solids (MLVSS) concentration of 2410 mg/L. If the aeration tank is 80 ft long by 40 ft wide and has wastewater to a depth of 16 ft, how many lb of MLVSS are under aeration?

175. An aeration tank is 110 ft long by 30 ft wide and has wastewater to a depth of 16 ft. If the aeration tank of this conventional activated sludge plant has a mixed liquor suspended solids (MLSS) concentration of 2740 mg/L, how many lb of MLSS are under aeration?

176. An aeration basin is 110 ft long by 50 ft wide and has wastewater to a depth of 16 ft. If the mixed liquor suspended solids (MLSS) concentration in the aeration tank is 2470 mg/L with a volatile solids content of 73%, how many lb of MLVSS are under aeration?

### Food-to-Microorganism (F/M) Ratio

177. An activated sludge aeration tank receives a primary effluent flow of 2.72 MGD with a BOD concentration of 198 mg/L. The mixed liquor volatile suspended solids (MLVSS) concentration is 2610 mg/L and the aeration tank volume is 480,000 gallons. What is the current food-to-microorganism (F/M) ratio?

178. An activated sludge aeration tank receives a primary effluent flow of 3,350,000 gpd with a BOD of 148 mg/L. The mixed liquor volatile suspended solids (MLVSS) concentration is 2510 mg/L and the aeration tank volume is 490,000 gallons. What is the current food-to-microorganism (F/M) ratio?

179. The flow to a 195,000-gallon oxidation ditch is 320,000 gpd. The BOD concentration of the wastewater is 180 mg/L. If the mixed liquor suspended solids (MLSS) concentration is 2540 mg/L with a volatile solids content of 72%, what is the food-to-microorganism (F/M) ratio?

180. The desired food-to-microorganism (F/M) ratio at an extended aeration activated sludge plant is 0.7 lb BOD per lb mixed liquor volatile suspended solids (MLVSS). If the primary effluent flow is 3.3 MGD and has a BOD of 181 mg/L, how many lb of MLVSS should be maintained in the aeration tank?

181. The desired food-to-microorganism (F/M) ratio at a particular activated sludge plant is 0.4 lb BOD per lb mixed liquor volatile suspended solids (MLVSS). If the primary effluent flow is 2,510,000 gpd and has a BOD concentration of 141 mg/L, how may lb of MLVSS should be maintained in the aeration tank?

## Sludge Age

182. An aeration tank has a total of 16,100 lb of mixed liquor suspended solids. If 2630 lb/day suspended solids enter the aeration tank in the primary effluent flow, what is the sludge age in the aeration tank?

183. An aeration tank contains 480,000 gallons of wastewater with a mixed liquor suspended solids (MLSS) concentration of 2720 mg/L. If the primary effluent flow is 2.9 MGD with a suspended solids concentration of 110 mg/L, what is the sludge age?

184. An aeration tank is 110 ft long by 50 ft wide and operates at a depth of 14 ft. The mixed liquor suspended solids (MLSS) concentration in the aeration tank is 2510 mg/L. If the influent flow to the tank is 2.88 MGD with a suspended solids concentration of 111 mg/L, what is the sludge age?

185. The mixed liquor suspended solids (MLSS) concentration in an aeration tank is 2960 mg/L. The aeration tank is 110 ft long by 50 ft wide and operates at a depth of 14 ft. If the influent flow to the tank is 1.98 MGD and has a suspended solids concentration of 110 mg/L, what is the sludge age?

186. An oxidation ditch has a volume of 211,000 gallons. The flow to the oxidation ditch is 270,000 gpd and has a suspended solids concentration of 205 mg/L. If the mixed liquor suspended solids (MLSS) concentration is 3810 mg/L, what is the sludge age in the oxidation ditch?

### Solids Retention Time (SRT)

187. An activated sludge system has a total of 29,100 lb of mixed liquor suspended solids. The concentration of suspended solids leaving the final clarifier in the effluent is calculated to be 400 lb/day. Suspended solids wasted from the final clarifier are 2920 lb/day. What is the solids retention time (in days)?

188. Determine the solids retention time (SRT) given the following data: *aeration tank volume*, 1,500,000 gallons; *mixed liquor suspended solids (MLSS)*, 2710 milligrams per liter; *final clarifier*, 106,000 gallons; *waste-activated sludge (WAS)*, 5870 milligrams per liter; *WAS pumping rate*, 72,000 gallons per day; *population equivalent flow*, 3.3 million gallons per day; *secondary effluent suspended solids*, 25 milligrams per liter; *average clarifier core suspended solids*, 1940 milligrams per liter.

189. An aeration tank has a volume of 460,000 gallons. The final clarifier has a volume of 178,000 gallons. The mixed liquor suspended solids (MLSS) concentration in the aeration tank is 2222 mg/L. If 1610 lb/day suspended solids are wasted and 240 lb/day suspended solids are in the secondary effluent, what is the solids retention time for the activated sludge system?

190. Calculate the solids retention time (SRT) given the following data:

| | |
|---|---|
| Aeration tank volume — 350,000 gal | MLSS — 2910 mg/L |
| Final clarifier — 125,000 gal | WAS — 6210 mg/L |
| Population equivalent flow — 1.4 MGD | Secondary effluent suspended solids — 16 mg/L |
| WAS pumping rate — 27,000 gpd | |

### Return Sludge Rate

191. The settleability test after 30 minutes indicates a sludge settling volume of 220 milliliters per liter (mL/L). Calculate the return-activated sludge (RAS) flow as a ratio to the secondary influent flow.

192. Given the following data, calculate the return-activated sludge (RAS) return rate:

| | |
|---|---|
| MLSS — 2480 mg/L | WAS — 61,000 |
| RAS SS — 7840 mg/L | |
| WAS SS — 7840 mg/L | Population equivalent — 3.6 MGD |

193. A total of 280 milliliters per liter (mL/L) sludge settled during a settle ability test after 30 minutes. The secondary influent flow is 3.25 MGD. Calculate the return-activated sludge (RAS) flow.

194. Given the following data, calculate the return-activated (RAS) return rate using the aeration tank solids balance equation:

MLSS — 2200 mg/L
RAS SS — 7520 mg/L
Population equivalent — 6.4 MGD

## Wasting Rate

195. The desired food-to-microorganism (F/M) ratio for an activated sludge system is 0.5 lb BOD per lb mixed liquor volatile suspended solids (MLVSS). It has been calculated that 3400 lb of BOD enter aeration tank daily. If the volatile solids content of the MLSS is 69%, how many lb MLSS are desired in the aeration tank?

196. Using a desired sludge age, it was calculated that 14,900 lb mixed liquor suspended solids (MLSS) are necessary in the aeration tank. If the aeration tank volume is 790,000 gallons and the MLSS concentration is 2710 mg/L, how many lb/day MLSS should be wasted?

197. Given the following data, determine the lb/day suspended solids to be wasted:

| | |
|---|---|
| Aeration tank volume — 1,200,000 gal | MLSS — 2200 mg/L |
| Influent flow — 3,100,000 gpd | % VS — 68% |
| BOD — 110 mg/L | |
| Desired F/M — 0.4 lb BOD/d/lb MLVSS | |

198. The desired sludge age for an activated sludge plant is 5.6 days. The aeration tank volume is 910,000 gallons. If 3220 lb/day suspended solids enter the aeration tank and the mixed liquor suspended solids (MLSS) concentration is 2900 mg/L, how many lb/day MLSS should be wasted?

199. The desired solids retention time (SRT) for an activated sludge plant is 9 days. The system contains 32,400 lb suspended solids. The secondary effluent flow is 3,220,000 gpd with a suspended solids content of 23 mg/L. How many lb/day waste-activated sludge (WAS) suspended solids must be wasted to maintain the desired SRT?

## WAS Pumping Rate

200. It has been determined that 5580 lb/day solids must be removed from a secondary system. If the return-activated sludge (RAS) suspended solids concentration is 6640 mg/L, what must the waste-activated sludge (WAS) pumping rate be (in million gallons per day)?

201. The waste-activated sludge (WAS) suspended solids concentration is 6200 mg/L. If 8710 lb/day dry solids are to be wasted, what must the WAS pumping rate be (in million gallons per day)?

202. Given the following data, calculate the WAS pumping rate required (in MGD):

| | |
|---|---|
| Desired SRT — 9 days | RAS SS — 7420 mg/L |
| Clarifier + aerator volume — 1.8 MG | Secondary effluent SS — 18 mg/L |
| MLSS — 2725 mg/L | Influent flow — 4.3 MGD |

203. Given the following data, calculate the WAS pumping rate required (in MGD):

| | |
|---|---|
| Desired SRT — 8.5 days | RAS SS — 6100 mg/L |
| Clarifier + aerator volume — 1.7 MG | Secondary effluent SS — 14 mg/L |
| MLSS — 2610 mg/L | Influent flow — 3.8 MGD |

### Oxidation Ditch Detention Time

204. An oxidation ditch has a volume of 166,000 gallons. If the flow to the oxidation ditch is 190,000 gpd, what is the detention time (in hours)?

205. An oxidation ditch receives a flow of 0.23 MGD. If the volume of the oxidation ditch is 370,000 gallons, what is the detention time (in hours)?

206. If the volume of an oxidation ditch is 420,000 gallons and the oxidation ditch receives a flow of 305,000 gpd, what is the detention time (in hours)?

207. The volume of an oxidation ditch is 210,000 gallons. If the oxidation ditch receives a flow of 310,000 gpd, what is the detention time (in hours)?

### General Activated Sludge Calculations

208. An aeration tank is 80 ft long by 40 ft wide and operates at an average depth of 15 ft. What is the capacity of the tank (in gallons)?

209. The BOD content of the wastewater entering an aeration tank is 220 mg/L. If the flow to the aeration tank is 1,720,000 gpd, what is the lb/day BOD loading?

210. The flow to a 220,000-gallon oxidation ditch is 399,000 gpd. The BOD concentration of the wastewater is 222 mg/L. If the mixed liquor suspended solids (MLSS) concentration is 3340 mg/L with a volatile solids content of 68%, what is the food-to-microorganism (F/M) ratio?

211. A clarifier has a diameter of 90 ft and an average depth of 12 ft. What is the capacity of the clarifier (in gallons)?

212. The daily flow to an aeration tank is 3,920,000 gpd. If the COD concentration of the influent wastewater is 160 mg/L, how many lb of COD are applied to the aeration tank daily?

213. An aeration tank contains 530,000 gallons of wastewater with a mixed liquor suspended solids (MLSS) concentration of 2700 mg/L. If the primary effluent flow is 1.8 MGD with a suspended solids concentration of 190 mg/L, what is the sludge age?

214. A mixed liquor sample is poured into a 2100-milliliter settlometer. After 30 minutes the settled sludge volume is 440 mL. If the plant flow rate ($Q$) is 6.1 MGD, what should the return sludge flow rate be (in gpm)?

215. The mixed liquor in a 0.45-million-gallon aeration tank has a suspended solids concentration (MLSS) of 2100 mg/L. The waste sludge is being removed at a rate of 0.120 MGD and has a concentration of 4920 mg/L. If the target MLSS is 2050 mg/L, what should the new waste sludge pumping rate be?

216. The mixed liquor in a 0.44-million-gallon aeration tank has a suspended solids concentration (MLSS) of 2090 mg/L. The waste sludge is being removed at a rate of 87.3 gpm and has a concentration of 4870 mg/L. If the target MLSS is 2170 mg/L, what should the new waste sludge pumping rate be (in gpm)?

217. An aeration tank has an MLSS concentration of 2210 mg/L. The volume of the tank is 0.66 million gallons. The plant flow rate is 3.25 MGD. The primary effluent suspended solids concentration is 131 mg/L. What is the sludge age?

218. The desired food-to-microorganism (F/M) ratio at a particular activated sludge plant is 0.6 lb BOD per lb mixed liquor volatile suspended solids (MLVSS). If the primary effluent flow is 2.88 MGD and has a BOD concentration of 146 mg/L, how many lb of MLVSS should be maintained in the aeration tank?

219. An oxidation ditch receives a flow of 0.31 MGD. If the volume of the oxidation ditch is 410,000 gallons, what is the detention time (in hours)?

220. The desired food-to-microorganism (F/M) ratio at a particular activated sludge plant is 0.8 lb COD per lb mixed liquor volatile suspended solids (MLVSS). If the primary effluent flow is 2,410,000 gpd and has a COD concentration of 161 mg/L, how many lb of MLVSS should be maintained in the aeration tank?

221. An aeration tank is 110 ft long by 40 ft wide and operates at a depth of 14 ft. The mixed liquor suspended solids (MLSS) concentration in the aeration tank is 2910 mg/L. If the influent flow to the tank is 1.4 MGD and contains a suspended solids concentration of 170 mg/L, what is the sludge age?

222. If the volume of an oxidation ditch is 620,000 gallons and the oxidation ditch receives a flow of 0.36 MGD, what is the detention time (in hours)?

223. An oxidation ditch has a volume of 260,000 gallons. The flow to the oxidation ditch is 0.4 MGD and has a suspended solids concentration of 200 mg/L. If the mixed liquor suspended solids (MLSS) concentration is 3980 mg/L, what is the sludge age in the oxidation ditch?

224. If the mixed liquor suspended solids (MLSS) concentration is 2710 mg/L and the aeration tank has a volume of 440,000 gallons, how many lb of suspended solids are in the aeration tank?

225. The desired food-to-microorganism (F/M) ratio at a conventional activated sludge plant is 0.4 lb BOD per lb mixed liquor volatile suspended solids (MLVSS). If the primary effluent flow is 2.88-MGD and has a BOD of 146 mg/L, how many lb of MLVSS should be maintained in the aeration tank?

226. The aeration tank of a conventional activated sludge plant has a mixed liquor volatile suspended solids concentration of 2510 mg/L. If the aeration tank is 110 ft long, 40 ft wide, and has wastewater to a depth of 18 ft, how many lb of MLVSS are in the aeration tank?

227. The mixed liquor suspended solids (MLSS) concentration in an aeration tank is 2740 mg/L. The aeration tank contains 710,000 gallons of wastewater. If the primary effluent flow is 1.86 MGD with a suspended solids concentration of 184 mg/L, what is the sludge age?

228. Determine the solids retention time (SRT) given the following data:

| | |
|---|---|
| Aeration tank volume — 1,410,000 gal | MLSS — 2680 mg/L |
| Final clarifier — 118,000 gal | WAs — 5870 mg/L |
| Population equivalent flow — 3.1 MGD | Secondary effluent SS — 20 mg/L |
| WAS — 76,000 gpd | Clarifier core SS — 1910 mg/L |

229. A settleability test after 30 minutes indicates a sludge settling volume of 231 milliliters per liter (mL/L). Calculate the return-activated sludge (RAS) flow as a ratio to the secondary influent flow.

230. The desired food-to-microorganism (F/M) ratio at an activated sludge plant is 0.5 lb BOD per lb mixed liquor volatile suspended solids (MLVSS). It was calculated that 3720 lb/day BOD enter the aeration tank. If the volatile solids content of the MLSS is 70%, how many lb MLSS are desired in the aeration tank?

231. The desired sludge age for a plant is 5 days. The aeration tank volume is 780,000 gallons. If 3740 lb/day suspended solids enter the aeration tank and the mixed liquor suspended solids (MLSS) concentration is 2810 mg/L, how many lb/day MLSS should be wasted?

232. It has been determined that 4110 lb/day of dry solids must be removed from a secondary system. If the return-activated sludge (RAS) suspended solids concentration is 6410 mg/L, what must the waste-activated sludge (WAS) pumping rate be (in million gallons per day)?

## Waste Treatment Ponds

### BOD Loading

233. Calculate the BOD loading (lb/day) on a pond if the influent flow is 410,000 gpd with a BOD concentration of 250 mg/L.

234. The BOD concentration of wastewater entering a pond is 161 mg/L. If the flow to the pond is 225,000 gpd, how many lb/day BOD enter the pond?

235. The flow to a waste treatment pond is 180 gpm. If the BOD concentration of the water is 223 mg/L, how many lb of BOD are applied to the pond daily?

236. The BOD concentration of influent wastewater to a waste treatment pond is 200 mg/L. If the flow to the pond is 130 gpm, how many lb of BOD are applied to the pond daily?

## Organic Loading Rate

237. A 7.8-acre pond receives a flow of 219,000 gpd. If the influent flow has a BOD content of 192 mg/L, what is the organic loading rate on the pond (in lb/day per acre)?

238. A pond has an average width of 420 ft and an average length of 740 ft. The flow to the pond is 167,000 gpd with a BOD content of 145 mg/L. What is the organic loading rate on the pond (in lb/day per acre)?

239. Flow to a pond is 72,000 gpd with a BOD content of 128 mg/L. The pond has an average width of 240 ft and an average length of 391 feet. What is the organic loading rate on the pond (in lb/day per acre)?

240. The maximum desired organic loading rate for a 15-acre pond is 22 lbs BOD/day/ac. If the influent flow to the pond has a BOD concentration of 189 mg/L, what is the maximum desirable flow to the pond (in million gallons per day)?

## BOD Removal Efficiency

241. The concentration of BOD entering a waste treatment pond is 210 mg/L. If the BOD in the pond effluent is 41 mg/L, what is the BOD removal efficiency of the pond?

242. The influent of a waste treatment pond has a BOD content of 267 mg/L. If the BOD content of the pond effluent is 140 mg/L, what is the BOD removal efficiency of the pond?

243. The concentration of BOD entering a waste treatment pond is 290 mg/L. If the BOD in the pond effluent is 44 mg/L, what is the BOD removal efficiency of the pond?

244. The concentration of BOD entering a waste treatment pond is 142 mg/L. If the BOD in the pond effluent is 58 mg/L, what is the BOD removal efficiency of the pond?

## Hydraulic Loading Rate

245. A 22-acre pond receives a flow of 3.6 acre-feet per day. What is the hydraulic loading rate on the pond (in in./day)?

246. A 16-acre pond receives a flow of 6 acre-feet per day. What is the hydraulic loading rate on the pond (in in./day)?

247. A waste treatment pond receives a flow of 2,410,000 gpd. If the surface area of the pond is 17 acres, what is the hydraulic loading (in in./day)?

248. A waste treatment pond receives a flow of 1,880,000 gpd. If the surface area of the pond is 16 acres, what is the hydraulic loading (in in./day)?

## Population Loading and Population Equivalent

249. A 5-acre wastewater pond serves a population of 1340 people. What is the population loading (people/acre) on the pond?

250. A wastewater pond serves a population of 5580 people. If the pond covers 19.1 acres, what is the population loading (people/acre) on the pond?

251. A wastewater flow of 0.8 MGD has a BOD concentration of 1640 mg/L. Using an average of 0.3 lb BOD per day per person, what is the population equivalent of this wastewater flow?

252. A 257,000-gpd wastewater flow has a BOD content of 2260 mg/L. Using an average of 0.2 lb BOD/day/person, what is the population equivalent of this flow?

## Detention Time

253. A waste treatment pond has a total volume of 19 acre-feet. If the flow to the pond is 0.44 acre-feet per day, what is the detention time of the pond (in days)?

254. A waste treatment pond is operated at a depth of 8 ft. The average width of the pond is 450 ft and the average length is 700 ft. If the flow to the pond is 0.3 MGD, what is the detention time (in days)?

255. The average width of the pond is 250 ft and the average length is 400 ft. A waste treatment pond is operated at a depth of 6 ft. If the flow to the pond is 72,000 gpd, what is the detention time (in days)?

256. A waste treatment pond has an average length of 700 ft, an average width of 410 ft, and a water depth of 5 ft. If the flow to the pond is 0.48 acre-feet per day what is the detention time for the pond (in days)?

## General Waste Treatment Pond Calculations

257. A wastewater treatment pond has an average length of 720 ft and an average width of 460 ft. If the flow rate to the pond is 310,000 gallons each day, and it is operated at a depth of 6 ft, what is the hydraulic detention time (in days)?

258. What is the detention time for a pond receiving an influent flow rate of 0.50 acre-feet each day? The pond has an average length of 705 ft and an average width of 430 ft. The operating depth of the pond is 50 inches.

259. A waste treatment pond has an average width of 395 ft and an average length of 698 ft. The influent flow rate to the pond is 0.16 MGD with a BOD concentration of 171 mg/L. What is the organic loading rate to the pond (in lb/day per acre)?

260. A pond 750 ft long by 435 ft wide receives an influent flow rate of 0.79 acre-feet per day. What is the hydraulic loading rate on the pond (in in./day)?

261. The BOD concentration of wastewater entering a pond is 192 mg/L. If the flow to the pond is 370,000 gpd, how many lb/day BOD enter the pond?

262. A 9.1-acre pond receives a flow of 285,000 gpd. If the influent flow has a BOD content of 240 mg/L, what is the organic rate on the pond (in lb/day per acre)?

263. The BOD entering a waste treatment pond is 220 mg/L. If the BOD concentration in the pond effluent is 44 mg/L, what is the BOD removal efficiency of the pond?

264. A 22-acre pond receives a flow of 3.8 acre-feet per day. What is the hydraulic loading on the pond (in in./day)?

265. The BOD concentration entering a waste treatment pond is 166 mg/L. If the BOD concentration in the pond effluent is 73 mg/L, what is the BOD removal efficiency of the pond?

266. The flow to a waste treatment pond is 210 gpm. If the BOD concentration of the water is 222 mg/L, how many lb of BOD are applied to the pond daily?

267. The flow to a pond is 80,000 gpd with a BOD content of 135 mg/L. The pond has an average width of 220 ft and an average length of 400 ft. What is the organic loading rate on the pond (in lb/day per acre)?

268. A waste treatment pond receives a flow of 1,980,000 gpd. If the surface area of the pond is 21 acres, what is the hydraulic loading (in in./day)?

269. A wastewater pond serves a population of 6200 people. If the area of the pond is 22 acres, what is the population loading on the pond?

270. A waste treatment pond has a total volume of 18.4 acre-feet. If the flow to the pond is 0.52 acre-feet per day, what is the detention time of the pond (in days)?

271. A wastewater flow of 0.9 MGD has a BOD concentration of 2910 mg/L. Using an average of 0.4 lb BOD per day per person, what is the population equivalent of this wastewater flow?

272. A waste treatment pond is operated at a depth of 6 ft. The average width of the pond is 440 ft and the average length is 730 ft. If the flow to the pond is 0.45 MGD, what is the detention time (in days)?

## Chemical Dosage

### Full-Strength Chemical Feed Rate

273. Determine the chlorinator setting (lb/day) required to treat a flow of 4.6 MGD with a chlorine dose of 3.4 mg/L.

274. The desired dosage for a dry polymer is 11 mg/L. If the flow to be treated is 1,680,000 gpd, how many lb/day polymer will be required?

275. To neutralize a sour digester, one lb of lime is to be added for every lb of volatile acids in the digester sludge. If the digester contains 200,000 gallons of sludge with a volatile acid level of 2200 mg/L, how many lb of lime should be added?

276. A total of 320 lb of chlorine was used during a 24-hour period to chlorinate a flow of 5.12 MGD. Given this dosage rate of lb/day, what was the dosage rate (in mg/L)?

### Chlorine Dose, Demand, and Residual

277. A secondary effluent is tested and found to have a chlorine demand of 4.9 mg/L. If the desired residual is 0.8 mg/L, what is the desired chlorine dose (in mg/L)?

278. The chlorine dosage for a secondary effluent is 8.8 mg/L. If the chlorine residual after 30 minutes of contact time is found to be 0.9 mg/L, what is the chlorine demand (in mg/L)?

279. The chlorine demand of a secondary effluent is 7.9 mg/L. If a chlorine residual of 0.6 mg/L is desired, what is the desired chlorine dosage (in mg/L)?

280. What should the chlorinator setting be (lb/day) to treat a flow of 4.0 MGD if the chlorine demand is 9 mg/L and a chlorine residual of 1.7 mg/L is desired?

### Less-Than-Full-Strength Chemical Feed Rate

281. A total chlorine dosage of 11.1 mg/L is required to treat a water unit. If the flow is 2.88 MGD and the hypochlorite has 65% available chlorine, how many lb/day of hypochlorite will be required?

282. The desired dose of polymer is 9.8 mg/L. The polymer provides 60% active polymer. If a flow of 4.1 MGD is to be treated, how many lb/day of the polymer compound will be required?

283. A wastewater flow of 1,724,000 gpd requires a chlorine dose of 19 mg/L. If hypochlorite (65% available chlorine) is to be used, how many lb/day of hypochlorite are required?

284. A total of 950 lb of 65% hypochlorite is used in a day. If the flow rate treated is 5.65 MGD, what is the chlorine dosage (in mg/L)?

## Percent Strength of Solutions

285. If 12 ounces of dry polymer are added to 16 gallons of water, what is the percent strength (by weight) of the polymer?

286. How many lb of dry polymer must be added to 24 gallons of water to make a 0.9% polymer solution?

287. If 160 grams of dry polymer are dissolved in 12 gallons of water, what percent strength is the solution? (1 gram = 0.0022 lb)

288. A 10% liquid polymer is to be used in making up a polymer solution. How many lb of liquid polymer should be mixed with water to produce 172 lb of a 0.5% polymer solution?

289. A 10% liquid polymer will be used in making up a solution. How many gallons of liquid polymer should be added to the water to make up 55 gallons of a 0.3% polymer solution? The liquid polymer has a specific gravity of 1.25. Assume the polymer solution has a specific gravity of 1.0.

290. How many gallons of 12% liquid polymer should be mixed with water to produce 110 gallons of a 0.7% polymer solution? The density of the polymer liquid is 11.2 lb/gal. Assume the density of the polymer solution is 8.34 lb/gal.

### Mixing Solutions of Different Strength

291. If 26 lb of a 10% solution are mixed with 110 lb of a 0.5% strength solution, what is the percent strength of the solution mixture?

292. If 6 gallons of a 12% strength solution are added to 30 gallons of a 0.4% strength solution, what is the percent strength of the solution mixture? Assume the 12% solution weighs 10.2 lb/gal and the 0.3% strength solution weighs 8.4 lb/gal.

293. If 12 gallons of a 10% strength solution are mixed with 42 gallons of a 0.28% strength solution, what is the percent strength of the solution mixture? Assume the 10% solution weighs 10.2 lb/gal and the 0.26% solution weighs 8.34 lb/gal.

## Solution Chemical Feeder Setting (gpd)

294. Jar tests indicate that the best liquid alum dose for a water unit is 10 mg/L. The flow to be treated is 4.10 MGD. Determine the gallons per day setting for the liquid alum chemical feeder if the liquid alum contains 5.88 lb of alum per gallon of solution.

295. Jar tests indicate that the best liquid alum dose for a water unit is 8 mg/L. The flow to be treated is 1,440,000 gpd. Determine the gallons per day setting for the liquid alum chemical feeder if the liquid alum contains 6.15 lb of alum per gallon of solution.

296. Jar tests indicate that the best liquid alum dose for a water unit is 11 mg/L. The flow to be treated is 2.13 MGD. Determine the gallons per day setting for the liquid alum chemical feeder if the liquid alum is a 60% solution. Assume the alum solution weighs 8.34 lb/gal.

297. The flow to the plant is 4,440,000 gpd. Jar testing indicates that the optimum alum dose is 9 mg/L. What should the gallons per day setting be for the solution feeder if the alum solution is a 60% solution? Assume the solution weighs 8.34 lb/gal.

## Percent Stroke Setting for Chemical Feed Pump

298. The required chemical pumping rate has been calculated to be 30 gpm. If the maximum pumping rate is 80 gpm, what should the percent stroke setting be?

299. The required chemical pumping rate has been calculated to be 22 gpm. If the maximum pumping rate is 80 gpm, what should the percent stroke setting be?

300. The required chemical pumping rate has been determined to be 14 gpm. What is the percent stroke setting if the maximum rate is 70 gpm?

301. The maximum pumping rate is 110 gpm. If the required pumping rate is 40 gpm, what is the percent stroke setting?

## Solution Chemical Feeder Setting (mL/min)

302. A desired solution feed rate is calculated to be 35 gpd. What is this feed rate expressed as milliliters per minute?

303. A desired solution feed rate is calculated to be 45 gpd. What is this feed rate expressed as milliliters per minute?

304. The optimum polymer dose has been determined to be 9 mg/L. The flow to be treated is 910,000 gpd. If the solution to be used contains 60% active polymer, what should the solution chemical feeder setting be (in milliliters per minute)? Assume the polymer solution weighs 8.34 lb/gal.

305. A flow to be treated is 1,420,000 gpd. The optimum polymer dose has been determined to be 11 mg/L. If the solution to be used contains 60% active polymer, what should the solution chemical feeder setting be (in milliliters per minute)? Assume the polymer solution weighs 8.34 lb/gal.

## Dry Chemical Feeder Calibration

306. Calculate the actual chemical feed rate (in lb/day) if a container is placed under a chemical feeder and a total of 2.1 lb is collected during a 30-minute period.

307. Calculate the actual chemical feed rate (in lb/day) if a bucket is placed under a chemical feeder and a total of 1 lb 8 ounces is collected during a 30-minute period.

308. To calibrate a chemical feeder, a container is first weighed (12 ounces) then placed under the chemical feeder. After 30 minutes, the container is weighed again. If the weight of the container with chemical is 2.10 lb, what is the actual chemical feed rate (in lb/day)?

309. A chemical feeder is to be calibrated. The container to be used to collect chemical is placed under the chemical feeder and weighed (0.5 lb). After 30 minutes, the weight of the container and chemical is found to be 2.5 lb. Based on this test, what is the actual chemical feed rate (in lb/day)?

## Solution Chemical Feeder Calibration

310. A calibration test is conducted for a solution chemical feeder. During 5 minutes, the solution feeder delivers a total of 770 mg/L. The polymer solution is a 1.4% solution. What is the polymer feed rate (in lb/day)? Assume the polymer solution weighs 8.34 lb/gal.

311. A calibration test is conducted for a solution chemical feeder. During the 5-minute test, the pump delivers 900 milliliters (mL) of a 1.2% polymer solution. What is the polymer dosage rate (in lb/day)? Assume the polymer solution weighs 8.34 lb/gal.

312. A calibration test is conducted for a solution chemical feeder. During the 5-minute test, the pump delivers 610 milliliters (mL) of a 1.3% polymer solution. The specific gravity of the polymer solution is 1.2. What is the polymer dosage rate (in lb/day)?

313. During a 5-minute test, a pump delivers 800 milliliters (mL) of a 0.5% polymer solution. A calibration test is conducted for the solution chemical feeder. The specific gravity of the polymer solution is 1.15. What is the polymer dosage rate (in lb/day)?

### Solution Chemical Feeder Calibration Based on Drop in Solution Tank Level

314. A pumping rate calibration test is conducted for a 3-minute period. The liquid level in the 4-foot-diameter solution tank is measured before and after the test. If the level drops 1.5 ft during a 3-minute test, what is the pumping rate (in gpm)?

315. A pumping rate calibration test is conducted for a 5-minute period. The liquid level in the 5-foot-diameter tank is measured before and after the test. If the level drops 15 inches during the test, what is the pumping rate (in gpm)?

316. A pump test indicates that a pump delivers 30 gpm during a 4-minute pumping test. The diameter of the solution tank is 5 ft. What was the expected drop (in feet) in solution level during the pumping test?

317. The liquid level in a 5-foot -diameter solution tank is measured before and after testing. A pumping rate calibration test is conducted for a 3-minute period. If the level drops 18 inches during the test, what is the pumping rate (in gpm)?

## Average Use Calculations

318. Based on the following data regarding the amount of chemical used each day for a week, what was the average lb/day chemical use during the week?

| | |
|---|---|
| Monday — 81 lb/d | Friday — 79 lb/d |
| Tuesday — 73 lb/d | Saturday — 83 lb/d |
| Wednesday — 74 lb/d | Sunday — 81 lb/d |
| Thursday — 66 lb/d | |

319. The average chemical use at a plant is 115 lb/day. If the chemical inventory in stock is 2300 lb, how many days' supply is this?

320. The chemical inventory in stock is 1002 lb. If the average chemical use at a plant is 66 lb/day, how many days' supply is this?

321. The average amount of polymer solution used each day at a treatment plant is 97 gpd. A chemical feed tank has a diameter of 5 ft and contains solution to a depth of 3 ft 4 inches. How many days' supply are represented by the solution in the tank?

## General Chemical Dosage Calculations

322. The desired dosage for a dry polymer is 11 mg/L. If the flow to be treated is 3,250,000 gpd, how many lb/day polymer will be required?

323. A total chlorine dosage of 7.1 mg/L is required to treat a particular water unit. If the flow is 3.24 MGD and the hypochlorite has 65% available chlorine, how many lb/day of hypochlorite will be required?

324. How many lb of dry polymer must be added to 32 gallons of water to make a 0.2% polymer solution?

325. Calculate the actual chemical feed rate (in lb/day) if a bucket is placed under a chemical feeder and a total of 1.9 lb is collected during a 30-minute period.

326. Jar tests indicate that the best liquid alum dose for a water unit is 12 mg/L. The flow to be treated is 2,750,000 gpd. Determine the gallons per day setting for the liquid alum chemical feeder if the liquid alum contains 5.88 lb of alum per gallon of solution.

327. A total of 379 lb of chlorine was used during a 24-hour period to chlorinate a flow of 5,115,000 gpd. Given this dosage rate of lb/day, what is the dosage rate (in mg/L)?

328. To calibrate a chemical feeder, a container is first weighed (12 ounces) then placed under the chemical feeder. After 30 minutes, the bucket is weighed again. If the weight of the bucket with the chemical is 2 lb 6 ounces, what is the actual chemical feed rate (in lb/day)?

329. The flow to a plant is 3,244,000 gpd. Jar testing indicates that the optimum alum dose is 10 mg/L. What should the gallons per day setting be for the solution feeder if the alum solution is a 60% solution? Assume the alum solution weighs 8.34 lb/gal.

330. The desired chemical pumping rate has been calculated at 32 gpm. If the minimum pumping rate is 90 gpm, what should the percent stroke setting be?

331. The chlorine dosage for a secondary effluent is 7.8 mg/L. If the chlorine residual after 30 minutes of contact time is found to be 0.5 mg/L, what is the chlorine demand (in mg/L)?

332. How many gallons of 12% liquid polymer should be mixed with water to produce 60 gallons of a 0.4% polymer solution? The density of the polymer liquid is 9.6 lb/gal. Assume the density of the polymer solution is 8.34 lb/gal.

333. A calibration test is conducted for a solution chemical feeder. During 5 minutes, the solution feeder delivers a total of 660 milliliters (mL). The polymer solution is a 1.2% solution. What is the lb/day feed rate? Assume the polymer solution weighs 8.34 lb/gal.

334. A pump operates at a rate of 30 gpm. How many feet will the liquid level be expected to drop after a 5-minute pumping test if the diameter of the solution tank is 6 ft?

335. The desired chemical pumping rate has been calculated to be 20 gpm. If the maximum pumping rate is 90 gpm, what should the percent stroke settling be?

336. What should the chlorinator setting be (lb/day) to treat a flow of 4.3 MGD if the chlorine demand is 8.7 mg/L and a chlorine residual of 0.9 mg/L is desired?

337. The average chemical use at a plant is 90 lb/day. If the chemical inventory in stock is 2100 lb, how many days' supply is this?

338. A desired solution feed rate is calculated to be 50 gpd. What is this feed rate expressed as milliliters per minute?

339. A calibration test is conducted for a solution chemical feeder. During a 5-minute test, the pump delivers 888 mL of the 0.9% polymer solution. What is the polymer dosage rate (in lb/day)? Assume the polymer solution weighs 8.34 lb/gal.

340. The flow to be treated is 3,220,000 gpd. The optimum polymer dose has been determined be 9 mg/L. If the solution to be used contains 60% active polymer, what should the solution chemical feeder setting be (in milliliters per minute)?

341. A pumping calibration test is conducted for a 3-minute period. The liquid level in the 4-foot-diameter solution tank is measured before and after the test. If the level drops 15 inches during the 3-minute test, what is the pumping rate (in gpm)?

342. A wastewater flow of 3,115,000 gpd requires a chlorine dose of 11.1 mg/L. If hypochlorite (65% available chlorine) is to be used, how many lb/day of hypochlorite are required?

343. If 6 gallons of a 12% strength solution are mixed with 22 gallons of a 0.3% strength solution, what is the percent strength of the solution mixture? Assume the 12% solution weighs 11.2 lb/gal and the 0.3% solution weighs 8.34 lb/gal.

## Sludge Production and Thickening

### Primary and Secondary Clarifier Solids Production

344. A primary clarifier receives a flow of 4.82 MGD with a suspended solids concentration of 291 mg/L. If the clarifier effluent has a suspended solids concentration of 131 mg/L, how many lb of dry solids are generated daily?

345. The suspended solids concentration of a primary influent is 315 mg/L and that of the primary effluent is 131 mg/L. How many lb of dry solids are produced if the flow is 3.9 MGD?

346. Influent flows at a rate of 2.1 MGD to the secondary system and has a BOD concentration of 260 mg/L. The secondary effluent contains 125 mg/L BOD. If the bacterial growth rate (*Y* value) for this plant is 0.6 lb suspended solids per lb BOD removed, how many lb of dry solids are produced each day by the secondary system?

347. The *Y* value for a treatment plant secondary system is 0.66 lb suspended solids per lb BOD removed. The influent to the secondary system is 2.84 MGD. If the BOD concentration of the secondary influent is 288 mg/L and the effluent BOD is 131 mg/L, how many lb of dry solids are produced each day by the secondary system?

### Percent Solids and Sludge Pumping

348. The total weight of a sludge sample is 31 grams (sludge sample only, not the dish). If the weight of the solids after drying is 0.71 grams, what is the percent total solids of the sludge?

349. A total of 8520 lb/day suspended solids is removed from a primary clarifier and pumped to a sludge thickener. If the sludge has a solids content of 4.2%, how many lb/day sludge are pumped to the thickener?

350. A total of 9350 gallons of sludge is pumped to a digester. If the sludge has a 5.5% solids content, how many lb/day solids are pumped to the digester? Assume the sludge weighs 8.34 lb/gal.

351. It is anticipated that 1490 lb/day suspended solids will be pumped from the primary clarifier of a new plant. If the primary clarifier sludge has a solids content of 5.3%, how many gpd sludge will be pumped from the clarifier? Assume the sludge weighs 8.34 lb/gal.

352. A primary sludge has a solids content of 4.4%. If 900 lb/day suspended solids are pumped from the primary clarifier, how many gallons per day sludge will be pumped from the clarifier? Assume the sludge weighs 8.34 lb/gal.

353. A total of 20,100 lb/day sludge is pumped to a thickener. The sludge has a 4.1% solids content. If the sludge is concentrated to 6% solids, what will be the expected lb/day sludge flow from the thickener?

354. A primary clarifier sludge has 5.1% solids content. If 2910 gpd of primary sludge are pumped to a thickener and the thickened sludge has a solids content of 6%, what would be the expected gallons per day flow of thickened sludge? Assume the primary sludge weighs 8.34 lb/gal and the thickened sludge weighs 8.64 lb/gal.

355. A primary clarifier sludge has a 3.4% solids content. A total of 12,4000-lb/day sludge is pumped to a thickener. If the sludge has been concentrated to 5.4% solids, what will be the lb/day sludge flow from the thickener?

356. The sludge from a primary clarifier has a solids content of 4.1%. The primary sludge is pumped at a rate of 6100 gpd to a thickener. If the thickened sludge has a solids content of 6.4%, what is the anticipated gallons per day sludge flow through the thickener? Assume the primary sludge weighs 8.34 lb/gal and the secondary sludge weighs 8.6 lb/gal.

## Gravity Thickening

357. A gravity thickener 28 ft in diameter receives a flow of 70 gpm primary sludge combined with a secondary effluent flow of 82 gpm. What is the hydraulic loading on the thickener (in gpd/sq ft)?

358. The primary sludge flow to a gravity thickener is 90 gpm. This is blended with a secondary effluent flow of 72 gallons per minute. If the thickener has a diameter of 28 ft, what is the hydraulic loading rate (in gpd/sq ft)?

359. A primary sludge flow equivalent to 122,000 gpd is pumped to a 44-foot-diameter gravity thickener. If the solids concentration of the sludge is 4.1%, what is the solids loading (in lb/day/sq ft)?

360. What is the solids loading (in lb/day/sq ft) on a gravity thickener if the primary sludge flow to the 32-foot-diameter gravity thickener is 60 gpm, with a solids concentration of 3.8%.

361. A gravity thickener 46 ft in diameter has a sludge blanket depth of 3.8 ft. If sludge is pumped from the bottom of the thickener at the rate of 28 gpm, what is the sludge detention time in the thickener (in days)?

362. A gravity thickener 40 ft in diameter has a sludge blanket depth of 4.3 ft. If the sludge is pumped from the bottom of the thickener at a rate of 31 gpm, what is the sludge detention time in the thickener (in hours)?

363. What is the efficiency of the gravity thickener if the influent flow to the thickener has a sludge solids concentration of 4% and the effluent flow has a sludge solids concentration of 0.9%?

364. The sludge flow entering a gravity thickener contains 3.5% sludge solids. The effluent from the thickener contains 0.8% sludge solids. What is the efficiency of the gravity thickener in removing sludge solids?

365. The sludge solids concentration of the influent flow to a gravity thickener is 3.3%. If the sludge withdrawn from the bottom of the thickener has a sludge solids concentration of 8.4%, what is the concentration factor?

366. The influent flow to a gravity thickener has a sludge solids concentration of 3.1%. What is the concentration factor if the sludge solids concentration of the sludge withdrawn from the thickener is 8.0%?

367. Given the data provided, determine whether the sludge blanket in the gravity thickener is expected to increase, decrease, or remain the same:

Sludge pumped to thickener — 130 gpm
Thickener sludge pumped from thickener — 50 gpm
Primary sludge solids — 3.6%
Thickened sludge solids — 8.1%
Thickener effluent suspended solids — 590 mg/L

368. Given the data provided, (a) determine whether the sludge blanket in the gravity thickener is expected to increase, decrease, or remain the same; and (b) in the case of an increase or decrease, determine how many lb/day this change should be:

Sludge pumped to thickener — 110 gpm
Thickener sludge pumped from thickener — 65 gpm
Primary sludge solids — 3.6%
Thickened sludge solids — 7.1%
Thickener effluent suspended solids — 520 mg/L

369. If solids are being stored at a rate of 9400 lb/day in a 30-foot-diameter gravity thickener, how many hours will it take the sludge blanket to rise 1.8 ft? The solids concentration of the thickened sludge is 6.6%.

370. Solids are being stored at a rate of 14,000 lb/day in a 30-foot-diameter gravity thickener. How many hours will it take the sludge blanket to rise 2.5 ft? The solids concentration of the thickened sludge is 8%.

371. After several hours of startup of a gravity thickener, the sludge blanket level is measured at 2.6 ft. The desired sludge blanket level is 6 ft. If the sludge solids are entering the thickener at a rate of 60 lb per minute, what is the desired sludge withdrawal rate (in gpm)? The thickened sludge solids concentration is 5.6%.

372. The sludge blanket level is measured at 3.3 ft after several hours of startup of a gravity thickener. If the desired sludge blanket level is 7 ft and the sludge solids are entering the thickener at a rate of 61 lb per minute, what is the desired sludge withdrawal rate (in gpm)? The thickened sludge solids concentration is 5.6%.

## Dissolved Air Flotation Thickening

373. A dissolved air flotation (DAF) thickener receives a sludge flow of 910 gpm. If the DAF unit is 40 ft in diameter, what is the hydraulic loading rate (in gallons per minute per square foot)?

374. A dissolved air flotation (DAF) thickener that is 32 ft in diameter receives a sludge flow of 660 gpm. What is the hydraulic loading rate (in gallons per minute per square foot)?

375. The sludge flow to a 40-foot-diameter dissolved air thickener is 170,000 gpd. If the influent waste-activated sludge (WAS) has a suspended solids concentration of 8420, what is the solids loading rate (in lb per hour per square foot)? Assume the sludge weighs 8.34 lb/gal.

376. The sludge flow to a dissolved air flotation (DAF) thickener is 120 gpm with a suspended solids concentration of 0.7%. If the DAF unit is 65 ft long by 20 ft wide, what is the solids loading rate (in lb per hour per square foot)? Assume the sludge weighs 8.34 lb/gal.

377. An air rotameter indicates a rate of supply of 9 cubic feet per minute (cfm) to the dissolved air flotation thickener. What is this air supply expressed as lb per hour?

378. The air rotameter for a dissolved air flotation (DAF) thickener indicates a supply rate of 12 cubic feet per minute (cfm) to the DAF unit. What is this air supply expressed as lb per hour?

379. A dissolved air flotation thickener receives a waste-activated sludge (WAS) flow of 85 gpm with a solids concentration of 8600 mg/L. If air is supplied at a rate of 8 cubic feet per minute (cfm), what is the air-to-solids ratio?

380. The sludge flow to a dissolved air flotation thickener is 60 gpm with a suspended solids concentration of 7800 mg/L. If the air supplied to the DAF unit is 5 cubic feet per minute (cfm), what is the air-to-solids ratio?

381. A dissolved air flotation thickener receives a sludge flow of 85 gpm. If the recycle rate is 90 gpm, what is the percent recycle rate?

382. The desired percent recycle rate for a dissolved air flotation unit is 112%. If the sludge flow to the thickener is 70 gpm, what should the recycle flow be (in million gallons per day)?

383. An 80-foot-diameter dissolved air flotation (DAF) thickener receives a sludge flow with a solids concentration of 7700 mg/L. If the effluent solids concentration is 240 mg/L, what is the solids removal efficiency?

384. The solids concentration of influent sludge to a dissolved air flotation unit is 8410 mg/L. If the thickened sludge solids concentration is 4.8%, what is the concentration factor?

## Centrifuge Thickening

385. A disc centrifuge receives a waste-activated sludge (WAS) flow of 40 gpm. What is the hydraulic loading on the unit (in gallons per hour)?

386. The waste-activated sludge (WAS) flow to a scroll centrifuge thickener is 86,400 gpd. What is the hydraulic loading on the thickener (in gallons per hour)?

387. The waste-activated sludge (WAS) flow to a basket centrifuge is 70 gpm. The basket run time is 30 minutes until the basket is full of solids. If it takes 1 minute to skim the solids out of the unit, what is the hydraulic loading rate on the unit (in gallons per hour)?

388. The sludge flow to a basket centrifuge is 78,000 gpd. The basket run time is 25 minutes until the flow to the unit must be stopped for the skimming operation. If skimming takes 2 minutes, what is the hydraulic loading on the unit (in gallons per hour)?

389. A scroll centrifuge receives a waste-activated sludge (WAS) flow of 110,000 gpd with a solids concentration of 7600 mg/L. What is the solids loading to the centrifuge (in lb per hour)?

390. The sludge flow to a basket thickener is 80 gpm with a solids concentration of 7500 mg/L. The basket operates 30 minutes before the flow must be stopped to the unit during the 2-minute skimming operation. What is the solids loading to the centrifuge (in lb per hour)?

391. A basket centrifuge with a 32-cubic-foot capacity receives a flow of 70 gpm. The influent sludge solids concentration is 7400 mg/L. The average solids concentration within the basket is 6.6%. What is the feed time for the centrifuge (in minutes)?

392. A basket centrifuge thickener has a capacity of 22 cubic feet. The sludge flows at a rate of 55 gpm to the thickener and has a solids concentration of 7600 mg/L. The average solids concentration within the basket is 9%. What is the feed time for the centrifuge (in minutes)?

393. The influent sludge solids concentration to a disc centrifuge is 8000 mg/L. If the sludge solids concentration of the centrifuge effluent (centrate) is 800 mg/L, what is the sludge solids removal efficiency?

394. Influent sludge to a scroll centrifuge has a sludge solids concentration of 9200 mg/L. If the centrifuge effluent has a sludge solids concentration of 0.25%, what is the sludge solids removal efficiency?

395. A total of 16 cubic feet of skimmed sludge and 4.0 cubic feet of knifed sludge is removed from a basket centrifuge. If the skimmed sludge has a solids concentration of 4.4% and the knifed sludge has a solids concentration of 8.0%, what is the percent solids concentration of the sludge mixture?

396. A total of 12 cubic feet of skimmed sludge and 4 cubic feet of knifed sludge is removed from a basket centrifuge. If the skimmed sludge has a solids concentration of 3.8% and the knifed sludge has a solids concentration of 8.0%, what is the percent solids concentration of the sludge mixture?

## General Sludge Production and Thickening Calculations

397. A solid bowl centrifuge receives 48,400 gallons of sludge daily. The sludge concentration before thickening is 0.8. How many lb of solids are received each day?

398. A gravity thickener receives a primary sludge flow rate of 170 gpm. If the thickener has a diameter of 24 ft, what is the hydraulic loading rate (in gpd/sq ft)?

399. The primary sludge flow rate to a 40-foot-diameter gravity thickener is 240 gpm. If the solids concentration is 1.3%, what is the solids loading rate (in lb per square feet)?

400. Waste-activated sludge (WAS) is pumped to a 34-foot-diameter dissolved air flotation thickener at a rate of 690 gpm. What is the hydraulic loading rate (in gallons per minute per square foot)?

401. Waste-activated sludge (WAS) is pumped to a 30-foot-diameter dissolved air flotation thickener at a rate of 130 gpm. If the concentration of solids is 0.98%, what is the solids loading rate (in lb per hour per square foot)?

402. The suspended solids content of a primary influent is 305 mg/L and that of the primary effluent is 121 mg/L. How many lb of solids are produced during a day in which the flow is 3.5 MGD?

403. The total weight of a sludge sample is 32 grams (sample weight only, not including the weight of the dish). If the weight of the solids after drying is 0.66 grams, what is the percent total solids of the sludge?

404. A primary clarifier sludge has 3.9% solids content. If primary sludge is pumped at a rate of 3750 gpd to a thickener and the thickened sludge has a solids content of 8%, what would be the expected flow of thickened sludge (in gallons per day)? Assume both sludges weigh 8.34 lb/gal.

405. A total of 9550 gallons of sludge is pumped to a digester daily. If the sludge has a 4.9% solids content, how many lb/day solids are pumped to the digester? Assume the sludge weighs 8.34 lb/gal.

406. Influent flows to a secondary system at a rate of 2.96 MGD and has a BOD concentration of 170 mg/L. The secondary effluent contains 38 mg/L BOD. If the bacteria growth rate ($Y$ value) for this plant is 0.5 lb suspended solids per lb BOD removed, what are the estimated lb of dry solids produced each day by the secondary system?

407. A gravity thickener 42 ft in diameter has a sludge blanket depth of 5 ft. If sludge is pumped from the bottom of the thickener at the rate of 32 gpm, what is the sludge detention time in the thickener (in hours)?

408. The solids concentration of the influent flow to a gravity thickener is 3.1%. If the sludge withdrawn from the bottom of the thickener has a solids concentration of 7.7%, what is the concentration factor?

409. The sludge flow to a 36-foot-diameter dissolved air thickener is 140,000 gpd. If the influent waste-activated sludge (WAS) has a suspended solids concentration of 7920 mg/L, what is the solids loading rate (in lb per hour per square foot)?

410. A 75-foot-diameter dissolved air flotation (DAF) thickener receives a sludge flow with a solids concentration of 7010 mg/L. If the effluent solids concentration is 230 mg/L, what is the solids removal efficiency?

411. The primary sludge flow to a gravity thickener is 70 gpm. This is blended with a 100-gpm secondary effluent flow. If the thickener has a diameter of 30 ft, what is the hydraulic loading rate (in gpd/sq ft)?

412. What is the efficiency of a gravity thickener if the influent flow to the thickener has a sludge solids concentration of 3.3% and the effluent flow has a sludge solids concentration of 0.3%?

413. The air supplied to a dissolved air flotation (DAF) thickener is 9 cubic feet per minute (cfm). What is this air supply expressed as lb per hour?

414. Given the data provided, determine whether the sludge blanket in the gravity thickener will increase, decrease, or remain the same:

Sludge pumped to thickener — 110 gpm
Thickener sludge pumped from thickener — 50 gpm
Primary sludge solids — 4%
Thickened sludge solids — 7.7%
Thickener effluent suspended solids — 700 mg/L

415. What is the solids loading on a gravity thickener (in lb/day/sq ft) if the primary sludge flow to the 32-foot-diameter thickener is 60 gpm with a solids concentration of 4.1%?

416. A dissolved air flotation unit is 60 ft long by 14 ft wide. If the unit receives a sludge flow of 190,000 gpd, what is the hydraulic loading rate (in gallons per minute per square foot)?

417. If solids are being stored at a rate of 9400 lb/day in a 26-foot-diameter gravity thickener, how many hours will it take the sludge blanket to rise 2.6 ft? The solids concentration of the thickened sludge is 6.9%.

418. The waste-activated sludge (WAS) flow rate to a scroll centrifuge thickener is 84,000 gpd. What is the hydraulic loading rate on the thickener (in gallons per hour)?

419. The sludge flow to a dissolved air flotation (DAF) thickener is 110 gpm. The solids concentration of the sludge is 0.81%. If the air supplied to the DAF unit is 6 cubic feet per minute (cfm), what is the air-to-solids ratio?

420. The desired percent recycle for a dissolved air flotation (DAF) unit is 112%. If the sludge flow to the thickener is 74 gpm, what should the recycle flow be (in million gallons per day)?

421. The sludge flow rate to a basket centrifuge is 79,000 gpd. The basket run time is 32 minutes until the flow to the unit must be stopped for the skimming operation. If skimming takes 2 minutes, what is the hydraulic loading on the unit (in gallons per hour)?

422. After several hours of startup of a gravity thickener, the sludge blanket level is measured at 2.5 ft. The desired sludge blanket level is 6 ft. If the sludge solids are entering the thickener at a rate of 48 lb per minute, what is the desired sludge withdrawal rate (in gpm)? The thickened sludge solids concentration is 8%.

423. A scroll centrifuge receives a waste-activated sludge (WAS) flow of 110,000 gpd with a solids concentration of 7110 mg/L. What is the solids loading to the centrifuge (in lb per hour)?

424. A basket centrifuge with a 34-cubic-foot capacity receives a flow of 70 gpm. The influent sludge solids concentration is 7300 mg/L. The average solids concentration within the basket is 6.6%. What is the feed time for the centrifuge (in minutes)?

425. The sludge flow to a basket thickener is 100 gpm with a solids concentration of 7900 mg/L. The basket operates 24 minutes before the flow must be stopped to the unit for a 1.5-minute skimming operation. What is the solids loading to the centrifuge (in lb per hour)?

426. A total of 12 cubic feet of skimmed sludge and 5 cubic feet of knifed sludge is removed from a basket centrifuge. If the skimmed sludge has a solids concentration of 3.9% and the knifed sludge has a solids concentration of 7.8%, what is the solids concentration of the sludge mixture?

## Digestion

### Mixing Different Sludge Mixtures

427. A primary sludge flow of 4240 gpd with a solids content of 5.9% is mixed with a thickened secondary sludge flow of 6810 gpd with a solids content of 3.5%. What is the percent solids content of the mixed sludge flow? Assume both sludges weigh 8.34 lb/gal.

428. Primary and thickened secondary sludges are to be mixed and sent to the digester. The 3510-gallons-per-day (gpd) primary sludge has a solids content of 5.2%, and the 5210-gpd thickened secondary sludge has a solids content of 4.1%. What would be the percent solids content of the mixed sludge? Assume both sludges weigh 8.3 lb/gal.

429. A primary sludge flow of 3910 gpd with a solids content of 6.3% is mixed with a thickened secondary sludge flow of 6690 gpd with a solids content of 4.9%. What is the percent solids of the combined sludge flow? Assume both sludges weigh 8.34 lb/gal.

430. Primary and secondary sludges are to be mixed and sent to the digester. The 2510-gallons-per-day (gpd) primary sludge has a solids content of 4.3%, and the 3600-gpd thickened secondary sludge has a solids content of 6.1%. What would be the percent solids content of the mixed sludge? Assume the 4.3% sludge weighs 8.35 lb/gal and the 6.1% sludge weighs 8.60 lb/gal.

### Sludge Volume Pumped

431. A piston pump discharges a total of 0.9 gallons per stroke. If the pump operates at 30 strokes per minute, what is the gallons per minute pumping rate? Assume the piston is 100% efficient and displaces 100% of its volume each stroke.

432. A sludge pump has a bore of 10 inches and a stroke length of 3 inches. If the pump operates at 30 strokes per minute, how many gallons per minute are pumped? Assume 100% efficiency.

433. A sludge pump has a bore of 8 inches and a stroke setting of 3 inches. The pump operates at 32 strokes per minute. If the pump operates a total of 120 minutes during a 24-hour period, what is the gallons per day pumping rate? Assume 100% efficiency.

434. A sludge pump has a bore of 12 inches and a stroke setting of 4 inches. The pump operates at 32 strokes per minute. If the pump operates a total of 140 minutes during a 24-hour period, what is the gallons per day pumping rate? Assume 100% efficiency.

## Sludge Pump Operating Time

435. The flow to a primary clarifier is 2.5 MGD. The influent suspended solids concentration is 240 mg/L and the effluent suspended solids concentration is 110 mg/L. If the sludge to be removed from the clarifier has a solids content of 3.5% and the sludge pumping rate is 32 gpm, how many minutes per hour should the pump operate?

436. The suspended solids concentration of a 1,870,000-gallons-per-day (gpd) influent flow to a primary clarifier is 210 mg/L. The primary clarifier effluent flow suspended solids concentration is 90 mg/L. If the sludge to be removed from the clarifier has a solids content of 3.6% and the sludge pumping rate is 28 gpm, how many minutes per hour should the pump operate?

437. A primary clarifier receives a flow of 3,480,000 gpd with a suspended solids concentration of 220 mg/L. The clarifier effluent has a suspended solids concentration of 96 mg/L. If the sludge to be removed from the clarifier has a solids content of 4.0%, and the sludge pumping rate is 38 gpm, how many minutes per hour should the pump operate?

438. Flow to a primary clarifier is 1.5 MGD with a suspended solids concentration of 222 mg/L. The clarifier effluent suspended solids concentration is 92 mg/L. The sludge to be removed from the clarifier has a solids content of 3.2%. If the sludge-pumping rate is 32 gpm, how many minutes per hour should the pump operate?

## Volatile Solids to the Digester

439. If 8620 lb/day of solids with a volatile solids content of 66% are sent to the digester, how many lb/day volatile solids are sent to the digester?

440. If 2810 lb/day of solids with a volatile solids content of 67% are sent to the digester, how many lb/day volatile solids are sent to the digester?

441. A total of 3720 gpd of sludge is to be pumped to a digester. If the sludge has a 5.8% solids content with 70% volatile solids, how many lb/day volatile solids are pumped to the digester? Assume the sludge weighs 8.34 lb/gal.

442. A sludge has a 7% solids content with 67% volatile solids. If 5115 gpd of sludge are to be pumped to the digester, how many lb/day of volatile solids are pumped in the digester?

## Seed Sludge Calculation

443. A digester has a capacity of 295,200 gallons. If the digester seed sludge is to be 24% of the digester capacity, how many gallons of seed sludge will be required?

444. A 40-foot-diameter digester has a side water depth of 24 ft. If the seed sludge to be used is 21% of the tank capacity, how many gallons of seed sludge will be required?

445. A 50-foot-diameter digester has a side water depth of 20 ft. If 62,200 gallons of seed sludge are to be used in starting up the digester, what percent of the digester volume will be seed sludge?

446. A digester, 40 ft in diameter, has a side water depth of 18 ft. If the digester seed sludge is to be 20% of the digester capacity, how many gallons of seed sludge will be required?

447. A total of 66,310 lb/day of sludge is pumped to a 120,000-gallon digester. The sludge being pumped to the digester has a total solids content of 5.3% and a volatile solids content of 70%. The sludge in the digester has a solids content of 6.3% with a 56% volatile solids content. What is the volatile solids loading on the digester (in volatile solids added/day/lb volatile solids in digester)?

448. A total of 22,310 gallons of digested sludge is in a digester. The digested sludge contains 6.2% total solids and 55% volatile solids. To maintain a volatile solids loading ratio of 0.06 lb volatile solids added/day/lb volatile solids under digestion, how many lb volatile solids may enter the digester daily?

449. A total of 60,400 lb/day sludge is pumped to a 96,000-gallon digester. The sludge pumped to the digester has a total solids content of 5.4% and a volatile solids content of 67%. The sludge in the digester has a solids content of 5% with a 58% volatile solids content. What is the volatile solids loading on the digester (in lb volatile solids added/day/lb volatile solids in the digester)?

450. The raw sludge flow to the new digester is expected to be 900 gpd. The raw sludge contains 5.5% solids and 69% volatile solids. The desired volatile solids loading ratio is 0.07 lb volatile solids added/day/lb volatile solids in the digester. How many gallons of seed sludge will be required if the seed sludge contains 8.2% solids with a 52% volatile solids content? Assume the seed sludge weighs 8.80 lb/gal.

## Digester Loading Rate

451. A digester 50 ft in diameter with a water depth of 22 ft receives 86,100 lb of raw sludge per day. If the sludge contains 5% solids with 70% volatile matter, what is the digester loading (in lb volatile solids added/day/cu ft volume)?

452. What is the digester loading (in lb volatile solids added per day per 1000 cubic feet) if a digester that is 40 ft in diameter with a liquid level of 22 ft receives 28,500 gpd of sludge with 5.6% solids and 72% volatile solids? Assume the sludge weighs 8.34 lb/gal.

453. A digester that is 50 ft in diameter with a liquid level of 20 ft receives 36,220 gpd of sludge with 5.6% solids and 68% volatile solids. What is the digester loading (in lb volatile solids added per day per 1000 cubic feet)? Assume the sludge weighs 8.34 lb/gal.

454. A digester that is 50 ft in diameter with a liquid level of 18 ft receives 16,200 gpd of sludge with 5.1% solids and 72% volatile solids. What is the digester loading (in lb volatile solids added per day per 1000 cubic feet)?

## Stored Digester Sludge

455. A total of 2600 gpd sludge is pumped to a digester. If the sludge has a total solids content of 5.7% and a volatile solids concentration of 66%, how many lb of digested sludge should be in the digester for this load? Assume the sludge weighs 8.34 lb/gal. Use a ratio of 1 lb volatile solids added per day per 10 lb of digested sludge.

456. A total of 6300 gpd of sludge is pumped to a digester. If the sludge has a solids concentration of 5% and a volatile solids content of 70%, how many lb of digested sludge should be in the digester for this load? Assume the sludge weighs 8.34 lb/gal. Use a ratio of 1 lb volatile solids added per day per 10 lb of digested sludge.

457. Sludge pumped to a digester has a solids concentration of 6.5% and a volatile solids content of 67%. If 5200 gpd of sludge are pumped to the digester, how many lb of digested sludge should be in the digester for this load? Assume the sludge weighs 8.34 lb/gal. Use a ratio of 1 lb volatile solids added per day per 10 lb of digested sludge.

458. A digester receives a flow of 3800 gallons of sludge over a 24-hour period. If the sludge has a solids content of 6% and a volatile solids concentration of 72%, how many lb of digested sludge should be in the digester for this load? Assume the sludge weighs 8.34 lb/gal. Use a ratio of 1 lb volatile solids added per day per 10 lb of digested sludge.

### Volatile Acids/Alkalinity Ratio

459. The volatile acid concentration of sludge in an anaerobic digester is 174 mg/L. If the measured alkalinity is 2220 mg/L, what is the volatile acids/alkalinity ratio?

460. The volatile acid concentration of sludge in an anaerobic digester is 160 mg/L. If the measured alkalinity is 2510 mg/L, what is the volatility acids/alkalinity ratio?

461. The measured alkalinity is 2410 mg/L. If the volatile acid concentration of sludge in the anaerobic digester is 144 mg/L, what is the volatile acids/alkalinity ratio?

462. The measured alkalinity is 2620 mg/L. If the volatile acid concentration of sludge in the anaerobic digester is 178 mg/L, what is the volatile acids/alkalinity ratio?

### Lime Neutralization

463. To neutralize a sour digester, 1 milligram per liter (mg/L) of lime is to be added for every milligram per liter of volatile acids in the digester sludge. If the digester contains 244,000 gallons of sludge with a volatile acid level of 2280 mg/L, how many lb of lime should be added?

464. To neutralize a sour digester, 1 milligram per liter (mg/L) of lime is to be added for every mg/L of volatile acids in the digester sludge. If the digester contains 200,000 gallons of sludge with a volatile acid level of 2010 mg/L, how many lb of lime should be added?

465. A digester contains 234,000 gallons of sludge with a volatile acid level of 2540 mg/L. To neutralize a sour digester, 1 mg/L of lime is to be added for every milligram per liter of volatile acids in the digester sludge. How many lb of lime should be added?

466. A digester sludge is found to have a volatile acids content of 2410 mg/L. If the digester volume is 182,000 gallons, how many lb of lime will be required for neutralization?

## Percent Volatile Solids Reduction

467. Sludge entering a digester has a volatile solids content of 68%. Sludge leaving the digester has a volatile solids content of 52%. What is the percent volatile solids reduction?

468. Sludge leaving a digester has a volatile solids content of 54%. Sludge entering the digester has a volatile solids content of 70%. What is the percent volatile solids reduction?

469. The raw sludge to a digester has a volatile solids content of 70%. The digested sludge volatile solids content is 55%. What is the percent volatile solids reduction?

470. The volatile solids content of a digested sludge is 54%. The raw sludge to a digester has a volatile solids content of 69%. What is the percent volatile solids reduction?

## Volatile Solids Destroyed

471. A flow of 3800 gpd sludge is pumped to a 36,500-cubic-foot digester. The solids concentration of the sludge is 6.3% with a volatile solids content of 73%. If the volatile solids reduction during digestion is 57%, how many lb/day volatile solids are destroyed per cubic foot of digester capacity? Assume the sludge weighs 8.34 lb/gal.

472. A flow of 4520 gpd sludge is pumped to a 34,000-cubic-foot digester. The solids concentration of the sludge is 7% with a volatile solids content of 69%. If the volatile solids reduction during digestion is 54%, how many lb/day volatile solids are destroyed per cubic foot of digester capacity? Assume the sludge weighs 8.34 lb/gal.

473. A 50-foot-diameter digester receives a sludge flow of 2600 gpd with a solids content of 5.6% and a volatile solids concentration of 72%. The volatile solids reduction during digestion is 52%. The digester operates at a level of 18 ft. What is the lb/day volatile solids reduction per cubic feet of digester capacity? Assume the sludge weighs 8.34 lb/gal.

474. The sludge flow to a 40-foot-diameter digester is 2800 gpd with a solids concentration of 6.1% and a volatile solids concentration of 65%. The digester is operated at a depth of 17 ft. If the volatile solids reduction during digestion is 56%, what is the lb/day volatile solids reduction per 1000 cubic foot of digester capacity? Assume the sludge weighs 8.34 lb/gal.

### Digester Gas Production

475. A digester gas meter reading indicates that, on average, 6600 cubic feet of gas are produced per day. If 500 lb/day volatile solids are destroyed, what is the digester gas production (in cubic feet gas per lb volatile solids destroyed)?

476. A total of 2110 lb of volatile solids is pumped to a digester daily. If the percent reduction of volatile solids due to digestion is 59%, and the average gas production for a day is 19,330 cubic feet, what is the daily gas production (in cubic feet per lb volatile solids destroyed)?

477. A total of 582 lb/day volatile solids is destroyed. If a digester gas meter reading indicates that 8710 cubic feet of gas are produced per day, on average, what is the digester gas production (in cubic feet per lb volatile solids destroyed)?

478. The percent reduction of volatile solids due to digestion is 54% and the average gas production for the day is 26,100 cubic feet. If 3320 lb of volatile solids are pumped to the digester daily, what is the daily gas production (in cubic feet per lb volatile solids destroyed)?

## Digestion Time

479. A 40-foot-diameter aerobic digester has a side water depth of 12 ft. The sludge flow to the digester is 9100 gpd. Calculate the hydraulic digestion time (in days).

480. An aerobic digester that is 40 ft in diameter has a side water depth of 10 ft. The sludge flow to the digester is 8250 gpd. Calculate the hydraulic digestion time (in days).

481. An aerobic digester is 80 ft long by 25 ft wide and has a side water depth of 12 ft. If the sludge flow to the digester is 7800 gpd, what is the hydraulic digestion time (in days)?

482. A sludge flow of 11,000 gpd has a solids content of 3.4%. As a result of thickening, the sludge flow is reduced to 5400 gpd with a 5% solids content. Compare the digestion times for the two different sludge flows to a digester 30 ft in diameter with a side water depth of 12 ft.

## Air Supply Requirements

483. The desired air supply rate for an aerobic digester was determined to be 0.06 cubic feet per minute per cubic foot digester capacity. What is the total cubic feet per minute of air required if the digester is 90 ft long by 30 ft wide with a side water depth of 12 ft?

484. An aerobic digester is 70 ft in diameter with a side water depth of 10 ft. If the desired air supply for this digester was determined to be 40 cubic feet per minute per 1000 cubic feet digester capacity, what is the total cubic feet per minute of air required for this digester?

485. Dissolved air concentrations recorded during a 5-minute test of an air-saturated sample of aerobic digester sludge are given below. Calculate the oxygen uptake (in mg/L per hour).

| Elapsed Time (min) | Dissolved Oxygen (mg/L) | Elapsed Time (min) | Dissolved Oxygen (mg/L) |
|---|---|---|---|
| 0 (at start) | 6.5 | 3 | 4.5 |
| 1 | 5.9 | 4 | 3.9 |
| 2 | 5.4 | 5 | 3.4 |

486. The dissolved air concentrations recorded during a 5-minute test of an air-saturated sample of aerobic digester sludge are given below. Calculate the oxygen uptake (in mg/L per hour).

| Elapsed Time (min) | Dissolved Oxygen (mg/L) | Elapsed Time (min) | Dissolved Oxygen (mg/L) |
|---|---|---|---|
| 0 (at start) | 7.3 | 3 | 4.3 |
| 1 | 6.8 | 4 | 4.2 |
| 2 | 5.7 | 5 | 3.7 |

## pH Adjustments

487. Jar tests indicate that 22 milligrams (mg) of caustic are required to raise the pH of a 1-liter sludge sample to 6.8. If the digester volume is 106,000 gallons, how many lb of caustic will be required for pH adjustment?

488. Jar tests indicate that 16 milligrams (mg) of caustic are required to raise the pH of a 1-liter sludge sample to 6.8. If the digester volume is 148,000 gallons, how many lb of caustic will be required for pH adjustment?

489. A 2-liter sample of digester sludge is used to determine the required caustic dosage for pH adjustment. If 64 milligrams (mg) of caustic are required for pH adjustment in the jar test and the digester volume is 54,000 gallons, how many lb of caustic will be required for pH adjustment?

490. A 2-liter sample of digested sludge is used to determine the required dosage for pH adjustment. A total of 90 milligrams (mg) caustic was used in the jar test. The aerobic digester is 60 ft in diameter with a side water depth of 14 ft. How many lb of caustic are required for pH adjustment of the digester?

## General Digester Calculations

491. Sludge is being pumped to a digester at a rate of 3.6 gpm. How many lb of volatile solids are being pumped to the digester daily if the sludge has 5.1% total solids content with 71% volatile solids?

492. A 55-foot-diameter anaerobic digester has a liquid depth of 22 ft. The unit receives 47,200 gallons of sludge daily with a solids content of 5.3%, of which 71% is volatile. What is the organic loading rate in the digester (in lb volatile solids added per cubic foot per day)?

493. The concentration of volatile acids in an anaerobic digester is 181 mg/L. If the concentration of alkalinity is measured to be 2120 mg/L, what is the volatile acids/alkalinity ratio?

494. If an anaerobic digester becomes sour, it must be neutralized. Adding lime to the unit can do this. The amount of lime to add is determined by the ratio of 1 milligram per liter (mg/L) of lime for every milligram per liter of volatile acids in the digester. If the volume of sludge in the digester is 756,000 liters and the volatile acids concentration is 1820 mg/L, how many kilograms of lime will be required to neutralize the digester?

495. An anaerobic digester has a raw sludge volatile solids content of 67%. The digested sludge has a volatile solids content of 55%. What is the percent reduction in the volatile solids content through the anaerobic digester?

496. Calculations indicate that 2600 kilograms (kg) of volatile solids will be required in the seed sludge. How many liters of seed sludge will be required if the sludge has a 9.5% solids content and 66% volatile solids and weighs 1.14 kg/L?

497. A total of 8200 gpd sludge is pumped to a digester. If the sludge has a solids content of 5.7% and a volatile solids concentration of 65%, how many lb of digested sludge should be in the digester for this load? Use a ratio of 1 lb volatile solids per day per 10 lb of digested sludge.

498. If 4400 lb/day solids with a volatile solids content of 67% are sent to the digester, how many lb of volatile solids are sent to the digester daily?

499. What is the digester loading (in lb volatile solids added per day per 1000 cubic feet) if a digester is 60 ft in diameter with a liquid level of 20 ft and receives 12,900 gpd of sludge with 5.4% solids and 65% volatile solids?

500. A primary sludge flow of 4040 gpd with a solids content of 5.4% is mixed with a thickened secondary sludge flow of 5820 gpd with a solids content of 3.3%. What is the percent solids content of the mixed sludge flow? Assume both sludges weigh 8.34 lb/gal.

501. A sludge pump has a bore or 8 inches and a stroke length of 6 inches. The counter indicates a total of 3500 revolutions during a 24-hour period. What is the pumping rate in gallons per day? Assume 100% efficiency.

502. A 60-foot-diameter digester has a typical side water depth of 24 ft. If 88,200 gallons seed sludge are to be used in starting up the digester, what percent of the digester volume will be seed sludge?

503. A flow of 3800 gpd sludge is pumped to a 36,000-cubic-foot digester. The solids content of the sludge is 4.1% with a volatile solids content of 70%. If the volatile solids reduction during digestion is 54%, how many lb/day volatile solids are destroyed per cubic foot of digester capacity? Assume the sludge weighs 8.34 lb/gal.

504. The volatile acid concentration of sludge in an anaerobic digester is 156 mg/L. If the measured alkalinity is 2310 mg/L, what is the volatile acids/alkalinity ratio?

505. To neutralize a sour digester, 1 milligram per liter (mg/L) of lime is to be added for every mg/L of volatile acid in the digester sludge. If the digester contains 240,000 gallons of sludge with a volatile acid level of 2240 mg/L, how many lb of lime should be added?

506. A 50-foot-diameter digester has a typical water depth of 22 ft. If the seed sludge to be used is 24% of the tank capacity, how many gallons of seed sludge will be required?

507. A total of 4310 gpd of sludge is to be pumped to the digester. If the sludge has 5.3% solids content with 72% volatile solids, how many lb/day volatile solids are pumped to the digester? Assume the sludge weighs 8.34 lb/gal.

508. Primary and thickened secondary sludges are to be mixed and sent to a digester. The 2940-gallons-per day (gpd) primary sludge has a solids content of 5.9%, and the 4720-gpd thickened secondary sludge has a solids content of 3.8%. What would be the percent solids content of the mixed sludge? Assume both sludges weigh 8.34 lb/gal.

509. A measured alkalinity is 2470 mg/L. If the volatile acid concentration of the sludge in an anaerobic digester is 150 mg/L, what is the volatile acids/alkalinity ratio?

510. A total of 42,250-lb/day sludge is pumped to a 94,000-gallon digester. The sludge being pumped to the digester has total solids content of 4% and volatile solids content of 60%. The sludge in the digester has a solids content of 6.0% with a 55% volatile solids content. What is the volatile solids loading on the digester (in lb volatile solids added/day/lb volatile solids in the digester)?

511. A sludge pump has a bore of 9 inches and a stroke length of 5 inches. If the pump operates at 30 strokes per minute, how many gallons per minute are pumped? Assume 100% efficiency.

512. What is the digester loading (in lb volatile solids added per day per 1000 cubic feet) if a digester that is 40 ft in diameter with a liquid level of 21 feet receives 19,200 gpd of sludge with 5% solids and 66% volatile solids?

513. Digester sludge is found to have a volatile acids content of 2200 mg/L. If the digester volume is 0.3 million gallons, how many lb of lime will be required for neutralization?

514. A digester gas meter reading indicates that, on average, 6760 cubic feet of gas are produced per day. If 580 lb/day volatile solids are destroyed, what is the digester gas production (in cubic feet gas per lb volatile solids destroyed)?

515. Sludge entering a digester has a volatile solids content of 67%. The sludge leaving the digester has a volatile solids content of 52%. What is the percent volatile solids reduction?

516. The raw sludge flow to a new digester is expected to be 1230 gpd. The raw sludge contains 4.1% solids and 66% volatile solids. The desired volatile solids loading ratio is 0.09 lb volatile solids added per lb volatile solids in the digester. How many gallons of seed sludge will be required if the seed sludge contains 7.5% solids with a 55% volatile solids content? Assume the raw sludge weighs 8.34 lb/gal and the seed sludge weighs 8.5 lb/gal.

517. Sludge leaving a digester has a volatile solids content of 56%. The sludge entering a digester has a volatile solids content of 70%. What is the percent volatile solids retention?

518. A 60-foot-diameter aerobic digester has a side water depth of 12 ft. The sludge flow to the digester is 9350 gpd. Calculate the digestion time (in days).

519. A total of 2610 lb of volatile solids is pumped to the digester daily. If the percent reduction of volatile solids due to digestion is 56% and the average gas production for the day is 22,400 cubic feet, what is the daily gas production (in cubic feet per lb volatile solids destroyed)?

520. The sludge flow to a 50-foot-diameter digester is 3200 gpd with a solids content of 6.4% and a volatile solids concentration of 68%. The digester is operated at a depth of 22 ft. If the volatile solids reduction during digestion is 55%, what is the digester capacity (in lb/day volatile solids reduction per 1000 cubic feet)?

521. The desired air supply rate for an aerobic digester is determined to be 0.05 cubic foot per minute per cubic foot digester capacity. What is the total cubic feet per minute of air required if the digester is 80 ft long by 20 ft wide and has a side water depth of 12 ft?

522. Jar testing indicates that 22 milligrams (mg) of caustic are required to raise the pH of a 1-liter sample to 7.0. If the digester volume is 120,000 gallons, how many lb of caustic will be required for pH adjustment?

523. Dissolved air concentration is taken by an air-saturated sample of digested sludge at 1-minute intervals. Given the results below, calculate the oxygen uptake (in mg/L per hour).

| Elapsed Time (min) | Dissolved Oxygen (mg/L) | Elapsed Time (min) | Dissolved Oxygen (mg/L) |
|---|---|---|---|
| 0 (at start) | 7.7 | 3 | 5.2 |
| 1 | 6.9 | 4 | 4.5 |
| 2 | 6.0 | 5 | 3.8 |

524. The flow to a primary clarifier is 2.2 MGD. The influent suspended solids concentration is 220 mg/L and the effluent suspended solids concentration is 101 mg/L. If the sludge to be removed from the clarifier has solids content of 3.0% and the sludge pumping rate is 25 gpm, how many minutes per hour should the pump operator?

525. A sludge flow of 12,000 gpd has a solids concentration of 2.6%. The solids concentration is increased to 4.6% as a result of thickening, and the reduced flow rate is 5400 gpd. Compare the digestion time for these two different sludge flows. The digester is 32 ft in diameter with a 24-foot operating depth.

## Sludge Dewatering

### Filter Press Dewatering

526. A filter press used to dewater digested primary sludge receives a flow of 1100 gallons over a 3-hour period. The sludge has a solids content of 3.8%. If the plate surface area is 140 square feet, what is the solids loading rate (in lb per hour per square foot)? Assume the sludge weighs 8.34 lb/gal.

527. A filter press used to dewater digested primary sludge receives a flow of 820 gallons over a 2-hour period. The solids content of the sludge is 5%. If the plate surface area is 160 square feet, what is the solids loading rate (in lb per hour per square foot)? Assume the sludge weighs 8.34 lb/gal.

528. A plate and frame filter press receives solids loading of 0.80 lb per hour per square foot. If the filtration time is 2 hours and the time required to remove the sludge cake and begin sludge feed to the press is 20 minutes, what is the net filter yield (in lb per hour per square foot)?

529. A plate and frame filer press receives a flow of 680 gallons of sludge over a 2-hour period. The solids concentration of the sludge is 3.9%. The surface area of the plate is 130 square feet. If the down time for sludge cake discharge is 20 minutes, what is the net filter yield (in lb per hour per square foot)? Assume the sludge weighs 8.34 lb/gal.

## Belt Filter Press Dewatering

530. A 6-foot-wide belt press receives a flow of 140 gpm of primary sludge. What is the hydraulic loading rate (in gallons per minute per feet)?

531. The amount of sludge to be dewatered by a belt filter press is 21,300 lb/day. If the belt filter press is to be operated 12 hours each day, what should be the sludge feed rate to the press (in lb per hour)?

532. The amount of sludge to be dewatered by a belt filter press is 23,100 lb/day. If the maximum feed rate that still provides an acceptable cake is 1800 lb per hour, how many hours per day should the belt remain in operation?

533. The sludge feed to a belt filter press is 160 gpm. If the total suspended solids concentration of the feed is 4.4%, what is the solids loading rate (in lb per hour)? Assume the sludge weighs 8.34 lb/gal.

534. The flocculant concentration for a belt filter press is 0.7%. If the flocculant feed rate is 4 gpm, what is the flocculation feed rate (in lb per hour)? Assume the flow is steady and continuous, and assume that the flocculant weighs 8.34 lb/gal.

## Vacuum Filter Dewatering

535. Digested sludge is applied to vacuum filter at a rate of 80 gpm, with a solids concentration of 5.1%. If the vacuum filter has a surface area of 320 square feet, what is the filter loading (in lb per hour per square foot)? Assume the sludge weighs 8.34 lb/gal.

536. The wet cake flow from a vacuum filter is 6810 lb per hour. If the filter area is 320 square feet and the percent solids in the cake is 31%, what is the filter yield (in lb per hour per square foot)?

537. A total of 5400 lb/day primary sludge solids is to be processed by a vacuum filter. The vacuum filter yield is 3.3 lb per hour per square foot. The solids recovery is 90%. If the area of the filter is 230 square feet, how many hours per day must the vacuum filter remain in operation to process this much solids?

538. The total lb of dry solids pumped to a vacuum filter during a 24-hour period is 18,310 lb/day. The vacuum filter is operated 10 hours per day. If the percent solids recovery is 91% and the filter area is 265 square feet, what is the filter yield (in lb per hour per square foot)?

539. The sludge feed to a vacuum filter is 85,230 lb per hour with a solids content of 5.9%. If the wet cake flow is 18,400 lb per hour with 20% solids content, what is the percent solids content and what is the percent solids recovery?

## Sand Drying Beds

540. A drying bed is 210 ft long by 22 ft wide. If sludge is applied to a depth of 8 inches, how many gallons of sludge are applied to the drying bed?

541. A drying bed is 240 ft long by 26 ft wide. If sludge is applied to a depth of 8 inches, how many gallons of sludge are applied to the drying beds?

542. A sludge bed is 190 ft long by 20 ft wide. A total of 168,000 lb of sludge is applied during each application of the sand drying bed. The sludge has a solids content of 4.6%. If the drying and removal cycle requires 21 days, what is the solids loading rate (in lb per year per square foot)?

543. A sludge drying bed is 220 ft long by 30 ft wide. The sludge is applied to a depth of 9 inches. The solids concentration of the sludge is 3.9%. If the drying and removal cycle requires 25 days, what is the solids loading rate to the beds (in lb per year per square foot)? Assume the sludge weighs 8.34 lb/gal.

544. Sludge is withdrawn from a digester that has a diameter of 50 ft. If the sludge is drawn down 2.4 ft, how many cubic feet will be sent to the drying beds?

545. A 50-foot-diameter digester has a drawdown of 14 inches. If the drying bed is 70 ft long by 40 ft wide, how many feet deep will the drying be as a result of the drawdown?

## Composting

546. If 4700 lb/day dewatered sludge with a solids content of 21% is mixed with 3800 lb/day compost with a 26% moisture content, what is the percent moisture of the blend?

547. The total dewatered digested primary sludge produced at a plant is 4800 lb/day with a solids content of 17%. The final compost to be used in blending has a moisture content of 27%. How much compost (lb/day) must be blended with the dewatered sludge to produce a mixture with a moisture content of 42%.

548. Compost is blended from bulking material and dewatered sludge. The bulking material is to be mixed with 7.4 cubic yards of dewatered sludge at a ratio (by volume) of 3:1. The solids content of the sludge is 19% and the solids content of the bulking material is 54%. If the bulk density of the sludge is 1710 lb per cubic yard ($lb/yd^3$) and the bulk density of the bulking material is 760 $lb/yd^3$, what is the percent solids of the compost blend?

549. A composting facility has an available capacity of 8200 cubic yards. If the composting cycle is 21 days, how many lb/day wet compost can be processed by this facility? Assume a compost bulk density of 1100 lb per cubic yard.

550. Compost is to be blended from wood chips and dewatered sludge. The wood chips are to be mixed with 12 cubic yards of dewatered sludge at a ratio (by volume) of 3:1. The solids content of the sludge is 16% and the solids content of the wood chips is 55%. If the bulk density of the sludge is 1720 lb per cubic yard ($lb/yd^3$) and the bulk density of the wood chips is 820 $lb/yd^3$, what is the percent solids of the compost blend?

551. Given the data provided, calculate the solids processing capability of the compost operation (in lb/day):

Cycle time — 21 d
Total available capacity — 7810 $yd^3$
% Solids of wet sludge — 19%
Mix ratio (by volume) of wood chips to sludge — 3
Wet compost bulk density — 1100 $lb/yd^3$
Wet sludge bulk density — 1720 $lb/yd^3$
Wet wood chips bulk density — 780 $lb/yd^3$

## General Sludge Dewatering Calculations

552. The sludge feed to a belt filter press is 150 gpm. If the total suspended solids concentration of the feed is 4.8%, what is the solids loading rate (in lb per hour)? Assume the sludge weighs 8.34 lb/gal.

553. Sludge is applied to a drying bed 220 ft long by 24 ft wide. The sludge has a total solids concentration of 3.3% and fills the bed to a depth of 10 inches. If it takes an average of 22 days for the sludge to dry and 1 day to remove the dried solids, how many lb of solids can be dried for every square foot of drying bed area each year?

554. A belt filter press receives a daily sludge flow of 0.20 million gallons. If the belt is 70 inches wide, what is the hydraulic loading rate on the unit for each foot of belt width (in gallons per minute per foot)?

555. A plate and frame filter press can process 960 gallons of sludge during its 140-minute operating cycle. If the sludge concentration is 4.2% and if the plate surface area is 150 square feet, how many lb of solids are pressed per hour for each square foot of plate surface area?

556. Thickened thermally conditioned sludge is pumped to a vacuum filter at a rate of 36 gpm. The vacuum area of the filter is 10 ft wide with a drum diameter of 9.6 ft. If the sludge concentration is 12%, what is the filter yield (in lb per hour per square foot)? Assume the sludge weight 8.34 lb/gal.

557. A vacuum filter produces an average of 3020 lb of sludge cake each hour. The total solids content of the cake produced is 40%. The sludge is being pumped to the filter at a rate of 24 gpm and at a concentration of 11%. If the sludge density is 8.50 lb/gal, what is the percent recovery of the filter?

558. The amount of sludge to be dewatered by a belt press is 25,200 lb/day. If the belt filter press is to be operated 12 hours each day, what should be the sludge feed rate to the press (in lb per hour)?

559. A filter press used to dewater digested primary sludge receives a flow of 800 gallons of sludge during a 2-hour period. The sludge has a solids content of 4.1%. If the plate surface area is 141 square feet, what is the solids loading rate (in lb per hour per square foot)? Assume the sludge weighs 8.34 lb/gal.

560. The sludge feed rate to belt filter press is 170 gpm. The total suspended solids concentration of the feed is 5%. The flocculation used for sludge conditioning is a 0.9% concentration, with a feed rate of 2.8 gpm. What is the flocculant dose expressed as lb flocculant per ton of solids treated?

561. A plate and frame filter press receives solids loading of 0.8 lb per hour per square foot. If the filtration time is 2 hours and the time required to remove the sludge cake and begin sludge feed to the press is 20 minutes, what is the net filter yield (in lb per hour per square feet)? Assume the sludge weighs 8.34 lb/gal.

562. Laboratory tests indicate that the total residue portion of a feed sludge sample is 24,300 mg/L. The total filterable residue is 740 mg/L. On this basis, what is the estimated total suspended solids concentration of the sludge sample?

563. Digested sludge is applied to a vacuum filter at a rate of 80 gpm with a solids concentration of 5.5%. If the vacuum filter has a surface area of 320 square feet, what is the filter loading (in lb per hour per square foot)? Assume the sludge weighs 8.34 lb/gal.

564. Wet cake flow from a vacuum filter is 7500 lb per hour. If the filter area is 320 square feet and the percent solids in the cake is 26%, what is the filter yield (in lb per hour per square foot)?

565. The amount of sludge to be dewatered by a belt filter is 28,300 lb/day. If the maximum feed rate that still provides an acceptable cake is 1800 lb per hours, how many hours per day should the belt remain in operation?

566. A total of 5700 lb/day primary sludge solids are to be processed by a vacuum filter. The vacuum filter yield is 3.1 lb per hour per square foot. The solids recovery is 92%. If the area of the filter is 280 square feet, how many hours per day must the vacuum filter remain in operation to process this amount of solids?

567. A drying bed is 220 ft long by 30 ft wide. If sludge is applied to a depth of 9 inches, how many gallons of sludge are applied to the drying bed?

568. The sludge feed to a vacuum filter is 91,000 lb/day, with a solids content of 5.3%. If the wet cake flow is 14,300 lb/day, with a 28% solids content, what is the percent solids recovery?

569. A sludge drying bed is 200 ft long by 25 ft wide. The sludge is applied to a depth of 8 inches. The solids concentration of the sludge is 5.1%. If the drying and removal cycle requires 20 days, what is the solids loading rate to the beds (in lb per year per square foot)? Assume the sludge weighs 8.34 lb/gal.

570. A drying bed is 190 ft long by 30 ft wide. If a 40-foot-diameter digester has a drawdown of 1 ft, how many feet deep will the drying bed be as a result of the drawdown?

571. A treatment plant produces a total of 6800 lb/day of dewatered digested primary sludge. The dewatered sludge has a solids concentration 25%. Final compost to be used in blending has a moisture content of 36%. How much compost (lb/day) must be blended with the dewatered sludge to produce a mixture with a moisture content of 55%?

572. Compost is to be blended from wood chips and dewatered sludge, The wood chips are to be mixed with 7.0 cubic yards of dewatered sludge at a ratio of 3 to 1. The solids content of the sludge is 16% and the solids content of the wood chips is 51%. If the bulk density of the sludge is 1710 lb per cubic yard ($lb/yd^3$) and the bulk density of the wood chips is 780 $lb/yd^3$, what is the percent solids of the compost blend?

573. A composting facility has an available capacity of 6350 cubic yards. If the composting cycle is 26 days, how many lb/day wet compost can be processed by this facility? How many tons per day is this? Assume a compost bulk density of 980 lb per cubic yard.

574. Given the data provided, calculate the dry sludge processing capability (in lb/day) of the compost operation:

Cycle time — 24 d
Total available capacity — 9000 $yd^3$
% Solids of wet sludge — 18%
Mix ratio (by volume) of wood chips to sludge — 3.1
Wet compost bulk density — 1100 $lb/yd^3$
Wet sludge bulk density — 1710 $lb/yd^3$
Wet wood chips bulk density — 800 $lb/yd^3$

## LABORATORY CALCULATIONS (WATER AND WASTEWATER) (PROBLEMS 1 TO 80)

### Estimating Faucet Flow

1. The flow from a faucet fills up a 1-gallon container in 66 seconds. What is the gallons per minute flow rate from the faucet?

2. A 1-gallon container was filled in 58 seconds. What was the gallons per minute flow rate from the faucet?

3. The flow from a faucet filled a 1-gallon container in 1 minute 22 seconds. What was the gpm flow rate from the faucet?

4. At a flow rate of 0.7 gpm, how many seconds will it take to fill a 1-gallon container?

5. How many seconds will it take to fill up a 1-gallon container if the flow rate from the faucet is 0.6 gpm?

## Service Line Flushing Time

6. How many minutes will it take to flush a 32-foot length of 3/4-inch-diameter service line if the flow rate through the line is 0.5 gpm?

7. How many minutes will it take to flush a 28-foot length of 3/4-inch diameter service line if the flow rate through the line is 0.6 gpm?

8. At a flow rate of 0.5 gpm, how long (in minutes and seconds) will it take to flush a 36-foot length of 3/4-inch service line?

9. How long (in minutes and seconds) will it take to flush a 22-foot length of 1/2-inch line if the flow rate through the line is 0.5 gallon per minute (gpm)?

## Solution Concentration

10. If 2.4 equivalents of a chemical are dissolved in 2 liters of solution, what is the normality of the solution?

11. An 800-milliliter solution contains 1.4 equivalents of a chemical. What is the normality of the solution?

12. How many milliliters of 0.5-*N* NaOH will react with 500 milliliters of 0.02-*N* HCl?

13. To prepare a sodium arsenite solution, 6 grams $NaAsO_2$ are to be dissolved in distilled water and diluted to 1 liter. If 4.88 grams $NaAsO_2$ are used in preparing the solution, how many milliliters solution should be prepared ?

14. To prepare a methyl red indicator solution, 100 milligrams (mg) methyl red sodium salt are to be dissolved and diluted to 100 milliliters. If 9816 mg of methyl red sodium salt are used to prepare the solution, how many milliliters solution should be prepared?

15. To prepare a copper sulfate solution, 110 grams $CuSO_4{\bullet}5H_2O$ are to be dissolved in distilled water and diluted to 1 liter. If 94.28 grams $CuSO_4{\bullet}5H_2O$ are used in preparing the solution, how many milliliters solution should be prepared?

16. If 2.6 equivalents of a chemical are dissolved in 1.9 liters of solution, what is the normality of the solution?

17. A 320-milliliter solution contains 1.5 equivalents of a chemical. What is the normality of the solution?

18. How many milliliters of 0.6-*N* NaOH will react with 780 mL of 0.05-*N* HCl?

## Biochemical Oxygen Demand (BOD)

19. Given the following information, determine the BOD of the wastewater after 5 days:

    Sample volume — 7 mL
    BOD bottle volume — 350 mL
    Initial DO of diluted sample — 8 mg/L
    DO of diluted sample — 3.7 mg/L

20. Results from a BOD test are provided. Calculate the BOD of the sample after 5 days:

Sample volume — 12 mL
BOD bottle volume — 320 mL
Initial DO of diluted sample — 8.7 mg/L
DO of diluted sample — 4.4 mg/L

21. Given the following primary effluent BOD test results (in mg/L), calculate the 7-day average:

| | |
|---|---|
| March 11 — 191 mg/L | March 15 — 206 mg/L |
| March 12 — 195 mg/L | March 16 — 202 mg/L |
| March 13 — 202 mg/L | March 17 — 195 mg/L |
| March 14 — 200 mg/L | |

22. Calculate the 7-day average primary effluent BOD for June 10, 11, and 12 given the BOD test results (in mg/L) provided:

| | | |
|---|---|---|
| June 1 — 208 mg/L | June 6 — 221 mg/L | June 11 — 211 mg/L |
| June 2 — 211 mg/L | June 7 — 226 mg/L | June 12 — 206 mg/L |
| June 3 — 204 mg/L | June 8 — 207 mg/L | June 13 — 221 mg/L |
| June 4 — 203 mg/L | June 9 — 202 mg/L | June 14 — 215 mg/L |
| June 5 — 214 mg/L | June 10 — 211 mg/L | June 15 — 217 mg/L |

## Settleability Solids

23. A settleability test is conducted on a sample of mixed liquor suspended solids (MLSS). What is the percent settleable solids if 440 millimeters (mL) settle in a 2000-mL graduated cylinder?

24. A 2000-milliliter (mL) sample of activated sludge is taken. If the settled sludge is measured as 320 mL, what is the percent settleable solids?

25. A settleability test is conducted on a sample of mixed liquor suspended solids (MLSS). What is the percent settleable solids if 410 milliliters (mL) settle in the 2000-mL graduated cylinder?

## Molarity and Moles

26. If 2.9 moles of solute are dissolved in 0.8 liter solution, what is the molarity of solution?

27. A 1.7-molar solution is to be prepared. If a 900-milliliter solution is to be prepared, how many moles solute will be required?

28. The atomic weight of calcium is 40. If 28 grams of calcium are used in making up a 1-liter solution, how many moles are used?

29. What is the molarity of a solution that has 0.5 moles solute dissolved in 1800 milliliters of solution?

## Sludge Total Solids and Volatile Solids

30. Given the information provided below, determine the percent total solids and percent of volatile solids in the sludge sample.

| | Sludge (Total Sample) (g) | After Drying (g) | After Burning (Ash) (g) |
|---|---|---|---|
| Weight of sample and dish | 85.78 | 26.27 | 24.31 |
| Weight of dish (tare weight) | 21.50 | 21.50 | 21.50 |

31. Given the information below, calculate the percent total solids and the percent volatile solids of the sludge sample.

| | Sludge (Total Sample) (g) | After Drying (g) | After Burning (Ash) (g) |
|---|---|---|---|
| Weight of sample and dish | 75.48 | 22.67 | 21.45 |
| Weight of dish (tare weight) | 20.80 | 20.80 | 20.80 |

32. A 100-milliliter sludge sample has been dried and burned. Given the information below, determine the percent volatile solids content of the sample, and determine the milligrams per liter concentration of the volatile solids.

| | After Drying (g) | After Burning (Ash) (g) |
|---|---|---|
| Weight of sample and crucible | 22.0188 | 22.0090 |
| Weight of crucible (tare weight) | 22.0022 | 22.0022 |

## Suspended Solids and Volatile Suspended Solids

33. Given the following information regarding a primary effluent sample, calculate the milligrams per liter suspended solids and the percent volatile suspended solids of the 50-milliliter sample.

| | After Drying (Before Burning) (g) | After Burning (Ash) (g) |
|---|---|---|
| Weight of sample and dish | 25.6818 | 25.6802 |
| Weight of dish (tare weight) | 25.6715 | 25.6715 |

34. Given the following information regarding a treatment plant influent sample, calculate the milligrams per liter suspended solids and the percent volatile suspended solids of the 25-milliliter sample.

| | After Drying (Before Burning) (g) | After Burning (Ash) (g) |
|---|---|---|
| Weight of sample and dish | 36.1588 | 36.1543 |
| Weight of dish (tare weight) | 36.1496 | 36.1496 |

35. Given the following information regarding a treatment plant influent sample, calculate the mg/L suspended solids, and the percent volatile suspended solids of the 25-mL sample.

| | After Drying (Before Burning) (g) | After Burning (Ash) (g) |
|---|---|---|
| Weight of sample and dish | 28.3196 | 28.3082 |
| Weight of dish (tare weight) | 28.2981 | 28.2981 |

## Sludge Volume Index (SVI) and Sludge Density Index (SDI)

36. After 30 minutes, a settleability test resulted in 220 milliliters of settleable solids in a 1-liter graduated cylinder. If the mixed liquor suspended solids (MLSS) concentration in the aeration tank is 2210 mg/L, what is the sludge volume index?

37. An activated sludge settleability test resulted in 410 milliliters settling in a 2-liter graduated cylinder. If the mixed liquor suspended solids (MLSS) concentration in the aeration tank is 2310 mg/L, what is the sludge volume index?

38. The mixed liquor suspended solids (MLSS) concentration in an aeration tank is 2110 mg/L. If the activated sludge settleability test indicates that 222 milliliters settled in a 1-liter graduated cylinder, what is the sludge density index?

39. Activated sludge in an aeration tank is found to have a concentration of mixed liquor suspended solids (MLSS) of 2140 mg/L. If the settleability test results in 186 milliliters settleable solids in a 1-liter graduated cylinder after 30 minutes, what is the sludge density index?

40. After 30 minutes, a settleability test resulted in 215 milliliters of settleable solids in a 1-liter graduated cylinder. If the mixed liquor suspended solids (MLSS) concentration in the aeration tank is 2510 mg/L, what is the sludge volume index?

## Temperature

41. The influent to a treatment plant has a temperature of 70˚F. What is this temperature expressed in degrees Celsius?

42. Convert 60˚ Fahrenheit to degrees Celsius.

43. The effluent of a treatment plant is 24˚C. What is this temperature expressed in degrees Fahrenheit?

44. What is 16˚C expressed in terms of degrees Fahrenheit?

## Chlorine Residual

45. The chlorine residual indicated by a color change is 0.5 mg/L. If 2 drops of sample water were used until the color was produced in the 10 milliliters of distilled water, what is the estimated actual chlorine residual of the sample?

46. The chlorine residual indicated by a color change produced during the drop-dilution method is 0.2 mg/L. If 3 drops of sample water were used until the color was produced in the 10 milliliters of distilled water, what is the estimated actual chlorine residual of the sample?

47. The drop-dilution method is used to estimate the actual chlorine residual of a sample. The chlorine residual indicated by the test is 0.3 mg/L. If 3 drops of sample water were required to produce the color change in the 10 milliliters of distilled water, what is the estimated actual chlorine residual of the sample?

## General Laboratory Calculations

48. How many minutes will it take to flush a 60-foot length of 3/4-inch-diameter service line if the flow through the line is 0.80 gpm?

49. Flow from a faucet fills up a gallon container in 45 seconds. What is the flow rate from the faucet (in gpm)?

50. If 2.3 equivalents of a chemical are dissolved in 1.4 liters of solution, what is the normality of the solution?

51. Flow from a faucet fills up a gallon container in 1 minute 10 seconds. What is the flow rate from the faucet (in gpm)?

52. The chlorine residual indicated by a color change is 0.4 mg/L. If 2 drops of sample water were used until the color was produced in the 10 milliliters of distilled water, what is the estimated actual chlorine residual of the sample?

53. How long (in minutes) will it take to flush a 75-foot length of 3/4-inch diameter service line if the flow through the line is 0.5 gpm?

54. To prepare a particular standard solution hydroxide (NaOH), 55 grams NaOH are to be dissolved in water and diluted to 1 liter. If 45.82 grams are weighed out, how many milliliters solution should be prepared?

55. At a flow rate of 0.8 gpm, how long (in minutes) should it take to fill a 1-gallon container?

56. A 780-milliliter solution contains 1.3 equivalents of a chemical. What is the normality of the solution?

57. The chlorine residual indicated by a color change produced during the drop-dilution method is 0.3 mg/L. If 3 drops of sample water were used until the color was produced in the 10 milliliters of distilled water, what is the estimated actual chlorine residual of the sample?

58. The influent to a treatment plant has a temperature of 73˚F. What is this temperature expressed in degrees Celsius?

59. At a flow rate of 0.5 gpm, how long (in minutes and seconds) will it take to flush a 60-foot length of 3/4-inch service line?

60. How many milliliters of 0.2-*N* NaOH will react with 500 mL of 0.01-*N* HCl?

61. Four drops of sample water are required to produce a color change in 10 milliliters of distilled water during the drop-dilution method of estimating chlorine residual. The chlorine residual indicated by the test is 0.3 mg/L. What is the estimated actual chlorine residual of the water tested?

62. To prepare a standard solution, the directions indicate that 7.7112 grams of chemical are to be weighed out and diluted to 1 liter. If 7.3132 grams of chemical are used in making the solution, how many milliliters solution should be prepared?

63. The effluent of a treatment plant is 16˚C. What is this temperature expressed in degrees Fahrenheit?

64. The influent to a treatment plant has a temperature of 78˚F. What is this temperature expressed in degrees Celsius?

65. A BOD test is done on a primary effluent sample. The initial dissolved oxygen (DO) was 7.12 mg/L and the residual DO was 4.37 mg/L. If the sample percentage used was 6%, what was the BOD of the sample?

66. A BOD test is done on a primary effluent sample. The initial dissolved oxygen (DO) was 7.28 mg/L and the residual DO was 4.18 mg/L. If the sample volume used was 10 milliliters (mL), what was the BOD of the 300-mL sample?

67. Use the following information to calculate the seeded BOD concentration:

| **Seeded Effluent** | **Seed Alone** |
|---|---|
| DO in = 7.31 mg/L | DO in = 7.61 mg/L |
| DO final = 4.58 mg/L | DO final = 4.87 mg/L |
| % Efficiency = 17% | % Seed = 4% |
| % Seed = 0.5% | |

68. A 2-liter volume of 0.05-*N* hydrochloric acid (HCl) solution is to be prepared. How many milliliters of 9-*N* hydrochloric acid must be diluted with water to prepare the desired volume?

69. It takes 8.2 mL of a solution of HCl to neutralize 10 milliliters of 4-*N* NaOH. What is the concentration of the HCl solution?

70. Calculate the percent removal of settleable solids if the settleable solids of the sedimentation tank influent are 16 milliliters and the settleable solids of the effluent are 0.8 milliliters per liter.

71. What is the molarity when 0.80 mole solute is dissolved in 1400 milliliters of solution?

72. A settleability test is conducted on a sample of mixed liquor suspended solids (MLSS). What is the percent settleable solids if 310 milliliters (mL) settle in a 2000-mL graduated cylinder?

73. If 2.3 equivalents of a chemical are dissolved in 1.30 liters solution, what is the normality of the solution?

74. Given the following information, determine the BOD of the wastewater after 5 days:

Sample volume — 6 mL
BOD bottle volume — 320 mL
Initial DO of diluted sample — 7.8 mg/L
DO of diluted sample — 4.4 mg/L

75. Given the information below, determine the percent total solids and percent of volatile solids in the sludge sample:

| | Sludge (Total Sample) (g) | After Drying (g) | After Burning (Ash) (g) |
|---|---|---|---|
| Weight of sample and dish | 80.28 | 27.80 | 26.18 |
| Weight of dish (tare weight) | 25.30 | 25.30 | 25.30 |

76. A settleability test indicates that after 30 minutes 222 milliliters of sludge settle in a 1-liter graduated cylinder. If the mixed liquor suspended solids (MLSS) concentration in the aerator is 2340 mg/L, what is the sludge volume index?

77. The influent to a treatment plant has a temperature of 75˚F. What is this temperature expressed in degrees Celsius?

78. The mixed liquor suspended solids (MLSS) concentration in an aerator is 2210 mg/L. If the activated sludge settleability test indicates that 188 milliliters settled in a 1-liter graduated cylinder, what is the sludge density index?

79. The influent to a treatment plant has a temperature of 17˚C. What is this temperature expressed in degrees Fahrenheit?

80. A settleability test is conducted on a sample of mixed liquor suspended solids (MLSS). What is the percent settleability solids if 300 milliliters (mL) settle in a 2000-mL graduated cylinder?

# Appendix A

## Workbook Answer Key

### BASIC MATH OPERATIONS (PROBLEMS 1 TO 43)

1. 660.65
2. 9.84268
3. 0.91
4. 8.5
5. 37.7
6. 0.75
7. 0.167
8. 0.375
9. 13/100
10. 9/10
11. 3/4
12. 49/200
13. 15%
14. 122%
15. 166%
16. 57.1%
17. 0
18. $x - 6 = 2$
    $x - 6 + 6 = 2 + 6$
    $x = 8$
19. $x - 4 = 9$
    $x = 13$
20. $x = 17 + 8 = 25$
21. $x = 15 - 10$
    $x = 5$
22. $3x/3 = 3 \times 2$
    $x = 6$
23. $(4)x/4 = 4 \times 10$
    $x = 40$
24. $x = 8/4$

$x = 2$

25. $x = 15/6$

    $x = 2.5$

26. $x + 10 - 10 = 2 - 10$

    $x = -8$

27. $x - 2 + 2 = -5 + 2$

    $x = -3$

28. $x = -8 - 4$

    $x = -12$

29. $x = -14 + 10$

    $x = -4$

30. $.5x = -5$

    $x = -10$

31. $9x = -1$

    $x = -1/9$

32. $x^2 = 6^2 = 6 \times 6 = 36$
33. $3 \times 3 \times 3 \times 3 = 81$
34. 1
35. 36:1
36. $2 \times 15 = 5x$

    $30 = 5x$

    $6 = x$

37. $3\text{ ft} \times 3\text{ ft} = 9\text{ ft}^2$
38. $5\text{ in.} \times 3\text{ in.} = 15\text{ in.}^2$
39. $5\text{ yd} \times 1\text{ yd} = 5\text{ yd}^2$
40. $= 22/7 \times 14/1\text{ ft} = 22/1 \times 2/1\text{ ft} = 44\text{ ft}$
41. $8\text{ in.} = 22/7\ D$

    $56\text{ in.} = 22\ D$

    $2.5\text{ in.} = D$

42. Area $= \pi r^2 = 22/7 \times 6^2\text{ in.} = 22/7 \times 36\text{ in.}^2/1 = 792/7 = 113\text{-}1/7\text{ in.}^2$
43. Area $= \pi r^2 = 22/7 \times 5^2\text{ in.}/1 = 22/7 \times 25\text{ in.}^2/1 = 550\text{ in.}^2/7 = 78\text{-}4/7\text{ in.}^2$

## FUNDAMENTAL OPERATIONS (WATER/WASTEWATER) (PROBLEMS 1 TO 342)

1. $0.785 \times 70\text{ ft} \times 70\text{ ft} \times 25\text{ ft} \times 7.48\text{ gal/ft}^3 = 719{,}295.5\text{ gal}$
2. $60\text{ ft} \times 20\text{ ft} \times 10\text{ ft} = 12{,}000\text{ ft}^3$
3. $20\text{ ft} \times 60\text{ ft} \times 12\text{ ft} \times 7.48\text{ gal/ft}^3 = 107{,}712\text{ gal}$
4. $20\text{ ft} \times 40\text{ ft} \times 12\text{ ft} \times 7.48\text{ ft}^3 = 71{,}808\text{ gal}$
5. $0.785 \times 60\text{ ft} \times 60\text{ ft} \times 12\text{ ft} \times 7.48\text{ gal/ft}^3 = 253{,}662\text{ gal}$
6. $20\text{ ft} \times 50\text{ ft} \times 16\text{ ft} \times 7.48\text{ gal/ft}^3 = 119{,}680\text{ gal}$
7. $4\text{ ft} \times 6\text{ ft} \times 340\text{ ft} = 8160\text{ ft}^3$
8. $0.785 \times 0.83\text{ ft} \times 0.83\text{ ft} \times 1600\text{ ft} \times 7.48\text{ gal/ft}^3 = 6472\text{ gal}$

9. $5\ \text{ft} + (10\ \text{ft}/2) \times 4\ \text{ft} \times 800\ \text{ft} \times 7.48\ \text{gal/ft}^3 = 7.5\ \text{ft} \times 4\ \text{ft} \times 800\ \text{ft} \times 7.48\ \text{gal/ft}^3 = 179{,}520\ \text{gal}$
10. $0.785 \times .66 \times .66 \times 2250\ \text{ft} \times 7.48\ \text{gal/ft}^3 = 5755\ \text{gal}$
11. $5\ \text{ft} \times 4\ \text{ft} \times 1200\ \text{ft} \times 7.48\ \text{gal/ft}^3 = 179{,}520\ \text{gal}$
12. $\dfrac{4\ \text{ft} \times 4\ \text{ft} \times 1200\ \text{ft}}{27\ \text{ft}^3/\text{yd}^3} = 711\ \text{yd}^3$
13. $500\ \text{yd} \times 1\ \text{yd} \times 1.33\ \text{yd} = 665\ \text{yd}^3$
14. $900\ \text{ft} \times 3\ \text{ft} \times 3\ \text{ft} = 8100\ \text{ft}^3$
15. $700\ \text{ft} \times 6.5\ \text{ft} \times 3.5\ \text{ft} = 15{,}925\ \text{ft}^3$
16. $0.785 \times 90\ \text{ft} \times 90\ \text{ft} \times 25\ \text{ft} \times 7.48\ \text{gal/ft}^3 = 1{,}189{,}040\ \text{gal}$
17. $80\ \text{ft} \times 16\ \text{ft} \times 20\ \text{ft} = 25{,}600\ \text{ft}^3$
18. $0.785 \times 0.67\ \text{ft} \times 0.67\ \text{ft} \times 4000\ \text{ft} \times 7.48\ \text{gal/ft}^3 = 10{,}543\ \text{gal}$
19. $1200\ \text{ft} \times 3\ \text{ft} \times 3\ \text{ft} = 10{,}800\ \text{ft}^3$
20. $\dfrac{3\ \text{ft} \times 4\ \text{ft} \times 1200\ \text{ft}}{27\ \text{ft}/\text{yd}^3} = 533\ \text{yd}^3$
21. $30\ \text{ft} \times 80\ \text{ft} \times 12\ \text{ft} \times 7.48\ \text{gal/ft}^3 = 215{,}424\ \text{gal}$
22. $8\ \text{ft} \times 3.5\ \text{ft} \times 3000\ \text{ft} \times 7.48\ \text{gal/ft}^3 = 628{,}320\ \text{gal}$
23. $0.785 \times 70\ \text{ft} \times 70\ \text{ft} \times 19\ \text{ft} \times 7.48\ \text{gal/ft}^3 = 546{,}665\ \text{gal}$
24. $0.785 \times 25\ \text{ft} \times 25\ \text{ft} \times 30\ \text{ft} \times 7.48\ \text{gal/ft}^3 = 110{,}096\ \text{gal}$
25. $2.4\ \text{ft} \times 3.7\ \text{ft} \times 2.5\ \text{fps} \times 60\ \text{sec/min} = 1332\ \text{cfm}$
26. $20\ \text{ft} \times 12\ \text{ft} \times 0.8\ \text{fpm} \times 7.48\ \text{gal/ft}^3 = 1436\ \text{gpm}$
27. $\dfrac{4\ \text{ft} + 6\ \text{ft}}{2} \times (3.3\ \text{ft} \times 130\ \text{fpm}) = 5(3.3\ \text{ft} \times 130\ \text{fpm}) = 2145\ \text{cfm}$
28. $0.785 \times 0.66 \times 0.66 \times 2.4\ \text{fps} \times 7.48\ \text{gal/ft}^3 \times 60\ \text{sec/min} = 368\ \text{gpm}$
29. $0.785 \times 3\ \text{ft} \times 3\ \text{ft} \times 4.7\ \text{fpm} \times 7.48\ \text{gal/ft}^3 = 248\ \text{gpm}$
30. $0.785 \times 0.83\ \text{ft} \times 0.83\ \text{ft} \times 3.1\ \text{fps} \times 7.48\ \text{gal/ft}^3 \times 60\ \text{sec/min} \times 0.5 = 376\ \text{gpm}$
31. $6\ \text{ft} \times 2.6\ \text{ft} \times x\ \text{fps} \times 60\ \text{sec/min} \times 7.48\ \text{gal/ft}^3 = 14{,}200\ \text{gpm},\ x = 2.03\ \text{ft}$
32. $0.785\ \text{x}\ 0.67 \times 0.67 \times x\ \text{fps} \times 7.48\ \text{gal/ft}^3 \times 60\ \text{sec/min} = 584\ \text{gpm},\ x = 3.7\ \text{fps}$
33. 550 ft/208 sec = 2.6 fps
34. $0.785 \times 0.83\ \text{ft} \times 0.83\ \text{ft} \times 2.4\ \text{fps} = 0.785 \times 0.67\ \text{ft} \times 0.67\ \text{ft} \times x\ \text{fps},\ x = 3.7\ \text{fps}$
35. 500 ft/92 sec = 5.4 fps
36. $0.785 \times 0.67 \times 0.67 \times 3.2\ \text{fps} = (0.785 \times 0.83\ \text{ft} \times 0.83\ \text{ft} \times x\ \text{fps}),\ x = 2.1\ \text{fps}$
37. 35.3 MGD/7 = 5 MGD
38. 121.4 MG/30 d = 4.0 MGD
39. $1{,}000{,}000 \times 0.165 = 165{,}000\ \text{gpd}$
40. 3,335,000 gal/1440 min = 2316 gpm
41. $8\ \text{cfs} \times 7.48\ \text{gal/ft}^3 \times 60\ \text{sec/min} = 3590\ \text{gpm}$
42. $35\ \text{gps} \times 60\ \text{sec/min} \times 1440\ \text{min/d} = 3{,}024{,}000\ \text{gpd}$
43. $\dfrac{4{,}570{,}000\ \text{gpd}}{1440\ \text{min/d} \times 7.48\ \text{gal/ft}^3} = 424\ \text{cfm}$
44. $6.6\ \text{MGD} \times 1.55\ \text{cfs/MGD} = 10.2\ \text{cfs}$
45. $\dfrac{445{,}875\ \text{cfd} \times 7.48\ \text{gal/ft}^3}{1440\ \text{min/d}} = 2316\ \text{gpm}$

46. $2450 \text{ gpm} \times 1440 \text{ min/d} = 3{,}528{,}000 \text{ gpd}$
47. $6 \text{ ft} \times 2.5 \text{ ft} \times x \text{ fps} \times 7.48 \text{ gal/ft}^3 \times 60 \text{ sec/min} = 14{,}800 \text{ gpm}, x = 2.2 \text{ fps}$
48. $4.6 \text{ ft} \times 3.4 \text{ ft} \times 3.6 \text{ fps} \times 60 \text{ sec/min} = 3378 \text{ cfm}$
49. $373.6/92 \text{ d} = 4.1 \text{ MGD}$
50. $12 \text{ ft} \times 12 \text{ ft} \times 0.67 \text{ fpm} \times 7.48 \text{ gal/ft}^3 = 722 \text{ gpm}$
51. $0.785 \times 0.67 \text{ ft} \times 0.67 \text{ ft} \times x \text{ fps} \times 7.48 \text{ gal/ft}^3 \times 60 \text{ sec/min} = 510 \text{ gpm}, x = 3.2 \text{ fps}$
52. $10 \text{ cfs} \times 7.48 \text{ gal/ft}^3 \times 60 \text{ sec/min} = 4488 \text{ gpm}$
53. $134.6/31 \text{ d} = 4.3 \text{ MGD}$
54. $5.2 \text{ MGD} \times 1.55 \text{ cfs/MGD} = 8.1 \text{ cfs}$
55. $0.785 \times 2 \text{ ft} \times 2 \text{ ft} \times 3.3 \text{ fpm} \times 7.48 \text{ gal/ft}^3 = 77.5 \text{ gpm}$
56. $\dfrac{1{,}825{,}000 \text{ gpd}}{1440 \text{ min/d} \times 7.48 \text{ gal/ft}^3} = 169 \text{ cfm}$
57. $0.785 \times 0.5 \text{ ft} \times 0.5 \text{ ft} \times 2.9 \text{ fps} \times 7.48 \text{ gal/ft}^3 \times 60 \text{ sec/min} = 255 \text{ gpm}$
58. $0.785 \times 0.83 \text{ ft} \times 0.83 \text{ ft} \times 2.6 \text{ fps} = 0.785 \times 0.67 \text{ ft} \times 0.67 \text{ ft} \times x \text{ fps} = 4.0 \text{ fps}$
59. $2225 \text{ gpm} \times 1440 \text{ min/d} = 3{,}204{,}000 \text{ gpd}$
60. $5{,}350{,}000 \text{ gal}/1440 \text{ min/d} = 3715 \text{ gpm}$
61. $2.5 \text{ mg/L} \times 5.5 \text{ MGD} \times 8.34 \text{ lb/gal} = 115 \text{ lb/d}$
62. $7.1 \text{ mg/L} \times 4.2 \text{ MGD} \times 8.34 \text{ lb/gal} = 249 \text{ lb/d}$
63. $11.8 \text{ mg/L} \times 4.8 \text{ MGD} \times 8.34 \text{ lb/gal} = 472 \text{ lb/d}$
64. $\dfrac{10 \text{ mg/L} \times 1.8 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.65} = 231 \text{ lb/d}$
65. $41 \text{ mg/L} \times 6.25 \text{ MGD} \times 8.34 \text{ lb/gal} = 214 \text{ lb/d}$
66. $60 \text{ mg/L} \times 0.086 \text{ MGD} \times 8.34 \text{ lb/gal} = 43 \text{ lb}$
67. $2220 \text{ mg/L} \times 0.225 \times 8.34 \text{ lb/gal} = 4166 \text{ lb}$
68. $\dfrac{8 \text{ mg/L} \times 0.83 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.65} = 85 \text{ lb/d}$
69. $450 \text{ mg/L} \times 1.84 \text{ MGD} \times 8.34 \text{ lb/gal} = 6906 \text{ lb/d}$
70. $25 \text{ mg/L} \times 2.90 \text{ MGD} \times 8.34 \text{ lb/gal} = 605 \text{ lb/d}$
71. $260 \text{ mg/L} \times 5.45 \text{ MGD} \times 8.34 \text{ lb/gal} = 11{,}818 \text{ lb/d}$
72. $144 \text{ mg/L} \times 3.66 \text{ MGD} \times 8.34 \text{ lb/gal} = 4396 \text{ lb/d}$
73. $290 \text{ mg/L} \times 3.31 \text{ MGD} \times 8.34 \text{ lb/gal} = 8006 \text{ lb/d}$
74. $152 \text{ mg/L} \times 5.7 \text{ MGD} \times 8.34 \text{ lb/gal} = 7226 \text{ lb/d}$
75. $188 \text{ mg/L} \times 1.92 \text{ MGD} \times 8.34 \text{ lb/gal} = 3010 \text{ lb/d SS}$
76. $184 \text{ mg/L} \times 1.88 \text{ MGD} \times 8.34 \text{ lb/d} = 2885 \text{ lb/d SS}$
77. $150 \text{ mg/L} \times 4.88 \text{ MGD} \times 8.34 \text{ lb/gal} = 6105 \text{ lb BOD per day}$
78. $205 \text{ mg/L} \times 2.13 \times 8.34 \text{ lb/gal} = 3642 \text{ solids}$
79. $115 \text{ mg/L} \times 4.20 \text{ MGD} \times 8.34 \text{ lb/gal} = 4028 \text{ lb/d}$
80. $2230 \text{ mg/L} \times 0.40 \text{ MG} \times 8.34 \text{ lb/gal} = 7439 \text{ lb SS}$
81. $1890 \text{ mg/L} \times 0.41 \text{ MG} \times 8.34 \text{ lb/gal} = 6463 \text{ lb MLVSS}$
82. $3125 \text{ mg/L} \times 0.18 \text{ MG} \times 8.34 \text{ lb/gal} = 4691 \text{ lb MLVSS}$
83. $2250 \text{ mg/L} \times 0.53 \text{ MG} \times 8.34 \text{ lb/gal} = 9945 \text{ lb MLSS}$
84. $2910 \text{ mg/L} \times 0.63 \text{ MG} \times 8.34 \text{ lb/gal} = 15{,}290 \text{ lb MLSS}$

85. $6150 \text{ mg/L} \times x \text{ MGD} \times 8.34 \text{ lb/gal} = 5200 \text{ lb/d}$

$x = 0.10 \text{ MGD}$

86. $6200 \text{ mg/L} \times x \text{ MGD} \times 8.34 \text{ lb/gal} = 4500 \text{ lb/d}$

a. $x = 0.09 \text{ MGD}$

b. $90{,}000 \text{ gpd} \div 1440 \text{ min/d} = 62.5 \text{ gpm}$

87. $6600 \text{ lb/d} \times x \text{ MGD} \times 8.34 \text{ lb/gal} = 6070 \text{ lb/d}$

$x = 0.11 \text{ MGD}$

$110{,}000 \text{ gpd} \div 1440 \text{ min/d} = 76 \text{ gpm}$

88. $6350 \text{ mg/L} \times x \text{ MGD} \times 8.34 \text{ lb/gal} = 7350 \text{ lb/d}$

$x = 0.14 \text{ MGD}$

$140{,}000 \text{ gpd} \div 1440 \text{ min/d} = 97 \text{ gpm}$

89. $7240 \text{ mg/L} \times x \text{ MGD} \times 8.34 \text{ lb/gal} = 5750 \text{ lb/d}$

$x = 0.10 \text{ MGD}$

$100{,}000 \text{ gpd} \div 1440 \text{ min/d} = 69 \text{ gpm}$

90. $2.5 \text{ mg} \times 3.65 \text{ MGD} \times 8.34 \text{ lb/gal} = 76.1 \text{ lb/d}$

91. $17 \text{ mg/L} \times 2.10 \text{ MGD} \times 8.34 \text{ lb/gal} = 298 \text{ lb BOD per day}$

92. $190 \text{ mg/L} \times 4.8 \text{ MGD} \times 8.34 \text{ lb/gal} = 7606 \text{ lb/d SS removed}$

93. $9.7 \text{ mg/L} \times 5.5 \text{ MGD} \times 8.34 \text{ lb/gal} = 445 \text{ lb/d}$

94. $305 \text{ mg/L} \times 3.5 \text{ MGD} \times 8.34 \text{ lb/gal} = 8903 \text{ lb/d}$

95. $$\frac{10 \text{ mg/L} \times 3.1 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.65} = 398 \text{ lb/d hypochlorite}$$

96. $210 \text{ mg/L} \times 3.44 \text{ MGD} \times 8.34 \text{ lb/gal} = 6025 \text{ lb/d solids}$

97. $60 \text{ mg/L} \times 0.09 \text{ MG} \times 8.34 \text{ lb/gal} = 45 \text{ lb chlorine}$

98. $2720 \text{ mg/L} \times 0.52 \text{ MG} \times 8.34 \text{ lb/gal} = 11{,}796 \text{ lb MLSS}$

99. $5870 \text{ mg/L} \times x \text{ MGD} \times 8.34 \text{ lb/gal} = 5480 \text{ lb/d}$

$x = 0.11 \text{ MGD}$

100. $120 \text{ mg/L} \times 3.312 \text{ MGD} \times 8.34 \text{ lb/gal} = 3315 \text{ lb BOD per day}$

101. $240 \text{ mg/L} \times 3.18 \text{ MGD} \times 8.34 \text{ lb/gal} = 6365 \text{ lb BOD}$

102. $196 \text{ mg/L} \times 1.7 \text{ MGD} \times 8.34 \text{ lb/gal} = 2779 \text{ lb BOD removed per day}$

103. $x \text{ mg/L} \times 5.3 \text{ MGD} \times 8.34 \text{ lb/d} = 330 \text{ lb/d}$

$x = 7.5 \text{ mg/L}$

104. $5810 \text{ mg/L} \times x \text{ MGD} \times 8.34 \text{ lb/gal} = 5810 \text{ mg/L}$

$x = 0.12 \text{ MGD}$

$= 120{,}000 \text{ gpd} \div 1440 \text{ min/d} = 83 \text{ gpm}$

105. $$\frac{3{,}400{,}000 \text{ gpd}}{0.785 \times 100 \text{ ft} \times 100 \text{ ft}} = 433 \text{ gpd/ft}^2$$

106. $$\frac{4{,}525{,}000 \text{ gpd}}{0.785 \times 90 \text{ ft} \times 90 \text{ ft}} = 712 \text{ gpd/ft}^2$$

107. $$\frac{3{,}800{,}000 \text{ gpd}}{870{,}000 \text{ ft}^2} = 4.4 \text{ gpd/ft}^2$$

108. $$\frac{280{,}749 \text{ ft}^3/\text{d}}{696{,}960 \text{ ft}^2} \times 0.4 \text{ ft/d}$$

$0.4 \text{ ft/d} \times 12 \text{ in./ft} = 4.8 \text{ in./d}$

109. $\dfrac{5{,}280{,}000 \text{ gpd}}{0.785 \times 90 \text{ ft} \times 90 \text{ ft}} = 830 \text{ gpd/ft}^2$

110. $\dfrac{4.4 \text{ acre-ft/d}}{20 \text{ acre}} = 0.22 \text{ ft/d}$

$= 3$ in./d

111. $\dfrac{2{,}050{,}000 \text{ gpd}}{70 \text{ ft} \times 25 \text{ ft}} = 1171 \text{ gpd/ft}^2$

112. $\dfrac{2{,}440{,}000 \text{ gpd}}{0.785 \times 60 \text{ ft} \times 60 \text{ ft}} = 863 \text{ gpd/ft}^2$

113. $\dfrac{3{,}450{,}000 \text{ gpd}}{110 \text{ ft} \times 50 \text{ ft}} = 627 \text{ gpd/ft}^2$

114. $\dfrac{1{,}660{,}000 \text{ gpd}}{25 \text{ ft} \times 70 \text{ ft}} = 949 \text{ gpd/ft}^2$

115. $\dfrac{2{,}660{,}000 \text{ gpd}}{0.785 \times 70 \text{ ft} \times 70 \text{ ft}} = 691 \text{ gpd/ft}^2$

116. $\dfrac{2230 \text{ gpm}}{40 \text{ ft} \times 20 \text{ ft}} = 2.8 \text{ gpm/ft}^2$

117. $\dfrac{3100 \text{ gpm}}{40 \text{ ft} \times 25 \text{ ft}} = 3.1 \text{ gpm/ft}^2$

118. $\dfrac{2500 \text{ gpm}}{26 \text{ ft} \times 60 \text{ ft}} = 1.6 \text{ gpm/ft}^2$

119. $\dfrac{1528 \text{ gpm}}{40 \text{ ft} \times 20 \text{ ft}} = 1.9 \text{ gpm/ft}^2$

120. $\dfrac{2850 \text{ gpm}}{880 \text{ ft}^2} = 3.2 \text{ gpm/ft}^2$

121. $\dfrac{4750 \text{ gpm}}{14 \text{ ft} \times 14 \text{ ft}} = 24 \text{ gpm/ft}^2$

122. $\dfrac{4900 \text{ gpm}}{20 \text{ ft} \times 20 \text{ ft}} = 12 \text{ gpm/ft}^2$

123. $\dfrac{3400 \text{ gpm}}{25 \text{ ft} \times 15 \text{ ft}} = 9 \text{ gpm/ft}^2$

124. $\dfrac{3300 \text{ gpm}}{75 \text{ ft} \times 30 \text{ ft}} = 4.4 \text{ gpm/ft}^2$

125. $\dfrac{3800 \text{ gpm}}{15 \text{ ft} \times 20 \text{ ft}} = 12.6 \text{ gpm/ft}^2$

126. $\dfrac{3{,}770{,}000 \text{ gal}}{15 \text{ ft} \times 30 \text{ ft}} = 8378 \text{ gal/ft}^2$

127. $\dfrac{1{,}860{,}000 \text{ gal}}{20 \text{ ft} \times 15 \text{ ft}} = 6200 \text{ gal/ft}^2$

128. $\dfrac{3{,}880{,}000 \text{ gal}}{25 \text{ ft} \times 20 \text{ ft}} = 7760 \text{ gal/ft}^2$

129. $\dfrac{1{,}410{,}200 \text{ gal}}{20 \text{ ft} \times 14 \text{ ft}} = 5036 \text{ gal/ft}^2$

130. $\dfrac{5{,}425{,}000 \text{ gal}}{30 \text{ ft} \times 20 \text{ ft}} = 9042 \text{ gal/ft}^2$

131. $\dfrac{1{,}410{,}000 \text{ gpd}}{163 \text{ ft}} = 8650 \text{ gpd/ft}$

132. $\dfrac{2{,}120{,}000 \text{ gpd}}{3.14 \times 60 \text{ ft}} = 11{,}253 \text{ gpd/ft}$

133. $\dfrac{2{,}700{,}000 \text{ gpd}}{240 \text{ ft}} = 11{,}250 \text{ gpd/ft}$

134. $\dfrac{1400 \text{ gpm} \times 1440 \text{ min/d}}{3.14 \times 80 \text{ ft}} = 8025 \text{ gpd/ft}$

135. $\dfrac{2785 \text{ gpm}}{189 \text{ ft}} = 14.7 \text{ gpm/ft}$

136. $\dfrac{210 \text{ mg/L} \times 2.45 \text{ MGD} \times 8.34 \text{ lb/gal}}{25.1 \times 1000 \text{ ft}^3} = 171 \text{ lb BOD/d/1000 ft}^3$

137. $\dfrac{170 \text{ mg/L} \times 0.120 \text{ MGD} \times 8.34 \text{ lb/gal}}{3.5 \text{ acre}} = 49 \text{ lb BOD/d/acre}$

138. $\dfrac{120 \text{ mg/L} \times 2.85 \text{ MGD} \times 8.34 \text{ lb/gal}}{34 \times 1000 \text{ ft}^3} = 84 \text{ lb BOD/d/1000 ft}^3$

139. $\dfrac{140 \text{ mg/L} \times 2.20 \text{ MGD} \times 8.34 \text{ lb/gal}}{900 \times 1000 \text{ ft}^2} = 2.9 \text{ lb/BOD/d/1000 ft}^2$

140. $0.785 \times 90 \text{ ft} \times 90 \text{ ft} \times 4 \text{ ft} = 25{,}434$

$$\dfrac{150 \text{ mg/L} \times 3.5 \text{ MGD} \times 8.34 \text{ lb/gal}}{25.4 \times 1000 \text{ ft}^3} = 172 \text{ lb BOD/d/1000 ft}^3$$

141. $\dfrac{200 \text{ mg/L} \times 3.42 \text{ MGD} \times 8.34 \text{ lb/gal}}{1875 \text{ mg/L} \times 0.42 \text{ MG} \times 8.34 \text{ lb/gal}} = 0.9$

142. $\dfrac{190 \text{ mg/L} \times 3.24 \text{ MGD} \times 8.34 \text{ lb/gal}}{1710 \text{ mg/L} \times 0.28 \text{ MG} \times 8.34 \text{ lb/gal}} = 1.3$

143. $\dfrac{151 \text{ mg/L} \times 2.25 \text{ MGD} \times 8.34 \text{ lb/gal}}{x \text{ lb MLVSS}} = 0.9$

$x = 3148$ lb MLVSS

144. $\dfrac{160 \text{ mg/L} \times 2.10 \text{ MGD} \times 8.34 \text{ lb/gal}}{1900 \text{ mg/L} \times 0.255 \text{ MG} \times 8.34 \text{ lb/gal}} = 0.7$

145. $\dfrac{180 \text{ mg/L} \times 3.11 \text{ MGD} \times 8.34 \text{ lb/gal}}{x \text{ mg/L} \times 0.88 \text{ MG} \times 8.34 \text{ lb/gal}} = 0.5$

$x = 1262$ mg/L MLVSS

146. $$\frac{2650 \text{ mg/L} \times 3.60 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.785 \times 70 \text{ ft} \times 70 \text{ ft}} = 20.7 \text{ lb MLSS/d/ft}^2$$

147. $$\frac{2825 \text{ mg/L} \times 4.25 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.785 \times 80 \text{ ft} \times 80 \text{ ft}} = 19.9 \text{ lb MLSS/d/ft}^2$$

148. $$\frac{x \text{ mg/L} \times 3.61 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.785 \times 60 \text{ ft} \times 60 \text{ ft}} = 26 \text{ lb/d/ft}^2$$

$x = 2441$ mg/L MLSS

149. $$\frac{2210 \text{ mg/L} \times 3.3 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.785 \times 60 \text{ ft} \times 60 \text{ ft}} = 21.5 \text{ lb MLSS/d/ft}^2$$

150. $$\frac{x \text{ mg/L} \times 3.11 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.785 \times 60 \text{ ft} \times 60 \text{ ft}} = 20 \text{ lb MLSS/d/ft}^2$$

$x = 2174$ mg/L MLSS

151 $$\frac{12{,}110 \text{ lb VS/d}}{33{,}100 \text{ ft}^3} = 0.37 \text{ lb VS/d/ft}^3$$

152. $$\frac{124{,}000 \text{ lb/d} \times 0.065 \times 0.70}{0.785 \times 60 \text{ ft} \times 60 \text{ ft} \times 25 \text{ ft}} = 0.08 \text{ lb VS/d/ft}^3$$

153. $$\frac{141{,}000 \text{ lb/d} \times 0.06 \times 0.71}{0.785 \times 50 \text{ ft} \times 50 \text{ ft} \times 20 \text{ ft}} = 0.15 \text{ lb VS/d/ft}^3$$

154. $$\frac{21{,}200 \text{ gpd} \times 8.34 \text{ lb/gal} \times 0.055 \times 0.69}{0.785 \times 40 \text{ ft} \times 40 \text{ ft} \times 16 \text{ ft}} = 0.33 \text{ VS/d/ft}^3$$

155. $$\frac{22{,}000 \text{ gpd} \times 8.6 \text{ lb/gal} \times 0.052 \times 0.70}{0.785 \times 50 \text{ ft} \times 50 \text{ ft} \times 20 \text{ ft}} = 0.18 \text{ lb VS/d/ft}^3$$

156. $$\frac{2050 \text{ lb VS added/d}}{32{,}400 \text{ lb VS}} = 0.06$$

157. $$\frac{620 \text{ lb VS added/d}}{174{,}600 \text{ lb} \times 0.061 \times 0.65} = 0.09$$

158. $$\frac{63{,}200 \text{ lb/d} \times 0.055 \times 0.73}{115{,}000 \text{ gal} \times 8.34 \text{ lb/gal} \times 0.066 \times 0.59} = 0.07$$

159. $$\frac{x \text{ lb VS added/d}}{110{,}000 \text{ gal} \times 8.34 \text{ lb/gal} \times 0.059 \times 0.58} = 0.08$$

$x = 2511$ lb/d VS

160. $$\frac{7900 \text{ gpd} \times 8.34 \text{ lb/gal} \times 0.048 \times 0.73}{x \text{ lb VS}} = 0.06$$

$x = 38{,}477$ lb VS

161. 1733 people/5.3 acre = 327 people/acre

162. 4112 people/10 acre = 411 people/acre

163. $$\frac{1765 \text{ mg/L} \times 0.381 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.2 \text{ lb/d}} = 28{,}040 \text{ people}$$

164. $\dfrac{6000 \text{ people}}{x \text{ acre}} = 420 \text{ people/acre}$

$x = 14.3$ acre

165. $\dfrac{2210 \text{ mg/L} \times 0.100 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.2 \text{ lb/d}} = 9216 \text{ people}$

166. $\dfrac{2{,}250{,}000 \text{ gpd}}{0.785 \times 80 \text{ ft} \times 80 \text{ ft}} = 448 \text{ gpd/ft}^2$

167. $\dfrac{2960 \text{ gpm}}{190 \text{ ft}^2} = 15.6 \text{ gpm/ft}^2$

168. $\dfrac{2{,}100{,}000 \text{ gpd}}{3.14 \times 80 \text{ ft}} = 8360 \text{ gpd/ft}$

169. $\dfrac{3{,}300{,}000 \text{ gpd}}{0.785 \times 90 \text{ ft} \times 90 \text{ ft}} = 519 \text{ gpd/ft}^2$

170. $\dfrac{161 \text{ mg/L} \times 2.1 \text{ MGD} \times 8.34 \text{ lb/gal}}{x \text{ lb MLVSS}} = 0.7$

$x = 4028$ lb MLVSS

171. $\dfrac{500 \text{ lb/d VS added/d}}{182{,}000 \text{ lb} \times 0.064 \times 0.67} = 0.06$

172. $\dfrac{2760 \text{ mg/L} \times 3.58 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.785 \times 80 \text{ ft} \times 80 \text{ ft}} = 16 \text{ lb/d/ft}^2$

173. $\dfrac{115{,}000 \text{ lb/d} \times 0.071 \times 0.70}{0.785 \times 70 \text{ ft} \times 70 \text{ ft} \times 21 \text{ ft}} = 0.09$

174. $\dfrac{4.15 \text{ acre-ft/d}}{25 \text{ acre}} = 0.17 \text{ ft/d} \times 12 \text{ in./ft} = 2.0 \text{ in./d}$

175. $\dfrac{174 \text{ mg/L} \times 3.335 \text{ MGD} \times 8.3 \text{ lb/gal}}{x \text{ mg/L} \times 0.287 \text{ MG} \times 8.34 \text{ lb/gal}} = 0.5$

$x = 4033$ mg/L MLVSS

176. $\dfrac{2{,}000{,}000 \text{ gpd}}{80 \text{ ft} \times 25 \text{ ft}} = 1000 \text{ gpd/ft}^2$

177. $\dfrac{1{,}785{,}000 \text{ gal}}{25 \text{ ft} \times 20 \text{ ft}} = 3570 \text{ gal/ft}^2$

178. $\dfrac{150 \text{ mg/L} \times 2.69 \text{ MGD} \times 8.34 \text{ lb/gal}}{1920 \text{ mg/L} \times 0.31 \text{ MG} \times 8.34 \text{ lb/gal}} = 0.68$

179. $\dfrac{x \text{ lb VS added/d}}{24{,}500 \text{ gal} \times 8.34 \text{ lb/gal} \times 0.055 \times 0.56} = 0.09$

$x = 566$ lb/d

180. $\dfrac{3083 \text{ gpm}}{40 \text{ ft} \times 30 \text{ ft}} = 2.6 \text{ gpm/ft}^2$

181. $\dfrac{115\text{ mg/L} \times 3.3\text{ MGD} \times 8.34\text{ lb/gal}}{20.1 \times 1000\text{ ft}^3} = 157\text{ lb BOD/d/1000 ft}^3$

182. $\dfrac{2{,}560{,}000\text{ gpd}}{3.14 \times 80\text{ ft}} = 10{,}191\text{ gpd/ft}$

183. 1900 people/5.5 acre = 345 people/acre

184. $\dfrac{140\text{ mg/L} \times 2.44\text{ MGD} \times 8.34\text{ lb/gal}}{750 \times 1000\text{ ft}^2} = 3.8\text{ lb BOD/d/1000 ft}^2$

185. $\dfrac{2882\text{ gpm}}{40\text{ ft} \times 30\text{ ft}} = 2.4\text{ gpm/ft}^2$

186. $\dfrac{30\text{ ft} \times 16\text{ ft} \times 8\text{ ft} \times 7.48\text{ gal/ft}^3}{1007\text{ gpm}} = 29\text{ min}$

187. $\dfrac{80\text{ ft} \times 20\text{ ft} \times 12\text{ ft} \times 7.48\text{ gal/ft}^3}{75{,}000\text{ gph}} = 1.9\text{ hr}$

188. $\dfrac{3\text{ ft} \times 4\text{ ft} \times 3\text{ ft} \times 7.48\text{ gal/ft}^3}{6\text{ gpm} \times 60\text{ min/hr}} = 0.75\text{ hr}$

189. $\dfrac{0.785 \times 80\text{ ft} \times 80\text{ ft} \times 10\text{ ft} \times 7.48\text{ gal/ft}^3}{216{,}667\text{ gpd}} = 1.7\text{ hr}$

190. $\dfrac{500\text{ ft} \times 600\text{ ft} \times 6\text{ ft} \times 7.48\text{ gal/ft}^3}{222{,}500\text{ gpd}} = 60.5\text{ d}$

191. $\dfrac{12{,}300\text{ lb MLSS}}{2750\text{ lb/d}} = 4.5\text{ d}$

192. $\dfrac{2820\text{ mg/L MLSS} \times 0.49\text{ MG} \times 8.34\text{ lb/gal}}{132\text{ mg/L} \times 0.988\text{ MGD} \times 8.34\text{ lb/gal}} = 10.6\text{ d}$

193. $\dfrac{2850\text{ mg/L MLSS} \times 0.20\text{ MG} \times 8.34\text{ lb/gal}}{84\text{ mg/L} \times 1.52\text{ MGD} \times 8.34\text{ lb/gal}} = 4.5\text{ d}$

194. $\dfrac{x\text{ mg/L MLSS} \times 0.205\text{ MG} \times 8.34\text{ lb/gal}}{80\text{ mg/L} \times 2.10\text{ MGD} \times 8.34\text{ lb/gal}} = 6\text{ d}$

$x = 4917$ mg/L MLSS

195. $\dfrac{x\text{ lb MLSS}}{1610\text{ lb/d SS}} = 5.5\text{ d}$

$x = 8855$ lb MLSS

196. $\dfrac{3300\text{ mg/L} \times 0.50\text{ MG} \times 8.34\text{ lb/gal}}{1610\text{ lb/d wasted} + 340\text{ lb/d in SE}} = 7.1\text{ d}$

197. $\dfrac{2750\text{ mg/L MLSS} \times 0.360\text{ MG} \times 8.34\text{ lb/gal}}{(5410\text{ mg/L} \times 0.0192\text{ MG} \times 8.34\text{ lb/gal}) + (16\text{ mg/L SS} \times 2.35\text{ MGD} \times 8.34\text{ lb/gal})} =$

$$\dfrac{8257\text{ lb}}{866\text{ lb/d} + 314\text{ lb/d}} = 7.0\text{ d}$$

198. $$\frac{2550 \text{ mg/L MLSS} \times 1.8 \text{ MG} \times 8.34 \text{ lb/gal}}{(6240 \text{ mg/L} \times 0.085 \text{ MG} \times 8.34 \text{ lb/gal}) + (20 \text{ mg/L SS} \times 2.8 \text{ MGD} \times 8.34 \text{ lb/gal})} =$$

$$\frac{38{,}281 \text{ lb MLSS}}{4424 \text{ lb/d} + 467 \text{ lb/d}} = 8 \text{ d}$$

199. $$\frac{x \text{ mg/L} \times 0.970 \text{ MG} \times 8.34 \text{ lb/gal}}{(6340 \text{ mg/L} \times 0.032 \text{ MG} \times 8.34 \text{ lb/gal}) + (20 \text{ mg/L SS} \times 2.6 \text{ MGD} \times 8.34 \text{ lb/gal})} = 8 \text{ d}$$

$$\frac{x \text{ mg/L} \times 0.970 \text{ MG} \times 8.34 \text{ lb/gal}}{1692 \text{ lb/d} + 434 \text{ lb/d}} = 8 \text{ d}$$

$$\frac{x \text{ mg/L} \times 0.970 \text{ MG} \times 8.34 \text{ lb/gal}}{2126} = 8 \text{ d}$$

$x$ = 2100 mg/L MLSS

200. $$\frac{75 \text{ ft} \times 30 \text{ ft} \times 14 \text{ ft} \times 7.48 \text{ gal/ft}^3}{68{,}333 \text{ gph}} = 3.5 \text{ hr}$$

201. $$\frac{12{,}600 \text{ lb MLSS}}{2820 \text{ lb/d}} = 4.5 \text{ d}$$

202. $$\frac{3120 \text{ mg/L MLSS} \times 0.48 \text{ MG} \times 8.34 \text{ lb/gal}}{1640 \text{ lb/d wasted} + 320 \text{ lb/d}} = 6.4 \text{ d}$$

203. $$\frac{40 \text{ ft} \times 20 \text{ ft} \times 10 \text{ ft} \times 7.48 \text{ gal/ft}^3}{1264 \text{ gpm}} = 47 \text{ min}$$

204. $$\frac{2810 \text{ mg/L MLSS} \times 0.325 \text{ MG} \times 8.34 \text{ lb/gal}}{(6100 \text{ mg/L} \times 0.0189 \text{ MGD} \times 8.34 \text{ lb/gal}) + (18 \text{ mg/L} \times 2.4 \text{ MGD} \times 8.34 \text{ lb/gal})} =$$

$$\frac{7617 \text{ lb MLSS}}{962 \text{ lb/d} + 360 \text{ lb/d}} = 5.8 \text{ d}$$

205. $$\frac{3250 \text{ mg/L} \times 0.33 \text{ MG} \times 8.34 \text{ lb/gal}}{100 \text{ mg/L} \times 2.35 \text{ MGD} \times 8.34 \text{ lb/gal}} = 4.6 \text{ d}$$

206. $$\frac{2408 \text{ mg/L} \times 1.9 \text{ MG} \times 8.34 \text{ lb/gal}}{(6320 \text{ mg/L} \times 0.0712 \text{ MGD} \times 8.34 \text{ lb/gal}) + (25 \text{ mg/L} \times 2.85 \text{ MGD} \times 8.34 \text{ lb/gal})} =$$

$$\frac{38{,}157 \text{ lb}}{3753 \text{ lb/d} + 594 \text{ lb/d}} = 9.8 \text{ d}$$

207. $$\frac{2610 \text{ mg/L} \times 0.15 \text{ MG} \times 8.34 \text{ lb/gal}}{140 \text{ mg/L} \times 0.92 \text{ MGD} \times 8.34 \text{ lb/gal}} = 3 \text{ d}$$

208. $$\frac{0.785 \times 6 \text{ ft} \times 6 \text{ ft} \times 4 \text{ ft} \times 7.48 \text{ gal/ft}^3}{12 \text{ gpm}} = 70 \text{ min}$$

209. $$\frac{x \text{ lb MLSS}}{140 \text{ mg/L} \times 2.14 \text{ MGD} \times 8.34 \text{ lb/gal}} = 6 \text{ d}$$

$x$ = 14,992 lb MLSS

210. $\dfrac{400 \text{ ft} \times 440 \text{ ft} \times 6 \text{ ft} \times 7.48 \text{ gal/ft}^3}{200{,}000 \text{ gpd}} = 39.5$

211. $\dfrac{x \text{ mg/L MLSS} \times 0.64 \text{ MG} \times 8.34 \text{ lb/gal}}{(6310 \text{ mg/L} \times 0.034 \text{ MGD} \times 8.34 \text{ lb/gal}) + (12 \text{ mg/L} \times 2.92 \text{ MGD} \times 8.34 \text{ lb/gal})} = 8 \text{ d}$

$$\frac{x \text{ mg/L} \times 0.64 \text{ MG} \times 8.34 \text{ lb/gal}}{1789 \text{ lb/d} + 292 \text{ lb/d}} = 8 \text{ d}$$

$$\frac{x \text{ mg/L} \times 0.64 \text{ MG} \times 8.34 \text{ lb/gal}}{2081 \text{ lb/d}} = 8 \text{ d}$$

$$x = 3141 \text{ mg/L MLSS}$$

212. $\dfrac{89 \text{ mg/L removed}}{110 \text{ mg/L}} \times 100 = 81\%$

213. $\dfrac{216 \text{ mg/L removed}}{230 \text{ mg/L}} \times 100 = 94\%$

214. $\dfrac{200 \text{ mg/L removed}}{260 \text{ mg/L}} \times 100 = 77\%$

215. $\dfrac{175 \text{ mg/L removed}}{310 \text{ mg/L}} \times 100 = 56\%$

216. $4.9 = \dfrac{x \text{ lb/d solids}}{3700 \text{ gal} \times 8.34 \text{ lb/gal}} \times 100$

$x$ = 1512 lb/d solids

217. $\dfrac{0.87 \text{ g sludge}}{12.87 \text{ g sludge}} \times 100 = 6.8\%$

218. $\dfrac{1450 \text{ lb/d solids}}{x \text{ lb/d sludge}} \times 100 = 3.3\%$

$x$ = 43,939 lb/d

219. $4.4 = \dfrac{258 \text{ lb/d}}{x \text{ gpd} \times 8.34 \text{ lb/gal}} \times 100$

$x$ = 703 gpd

220. $3.6 = \dfrac{x \text{ lb/d solids}}{291{,}000 \text{ lb/d sludge}} \times 100$

$x$ = 10,476 lb/d solids

221. $\dfrac{\left(3100 \text{ gpd} \times 8.34 \text{ lb/gal} \times \dfrac{4.4}{100}\right) + \left(4100 \text{ gpd} \times 8.34 \text{ lb/gal} \times \dfrac{3.6}{100}\right)}{(3100 \text{ gpd} \times 8.34 \text{ lb/gal}) + (4100 \text{ gpd} \times 8.34 \text{ lb/gal})} \times 100 =$

$$\frac{1138 \text{ lb/d solids} + 1231 \text{ lb/d solids}}{25{,}854 \text{ lb/d sludge} + 34{,}194 \text{ lb/d sludge}} \times 100 =$$

$$\frac{2369 \text{ lb/d solids}}{60{,}048 \text{ lb/d sludge}} \times 100 = 3.9\%$$

222. $$\frac{\left(8100 \text{ gpd} \times 8.34 \text{ lb/gal} \times \frac{5.1}{100}\right) + \left(7000 \text{ gpd} \times 8.34 \text{ lb/gal} \times \frac{4.1}{100}\right)}{(8100 \text{ gpd} \times 8.34 \text{ lb/gal}) + (7000 \text{ gpd} \times 8.34 \text{ lb/gal})} \times 100 =$$

$$\frac{3445 \text{ lb/d solids} + 2394 \text{ lb/d solids}}{67{,}554 \text{ lb/d sludge} + 58{,}380 \text{ lb/d sludge}} \times 100 =$$

$$\frac{5839 \text{ lb/d solids}}{125{,}934 \text{ lb/d sludge}} \times 100 = 4.6\%$$

223. $$\frac{\left(4750 \text{ gpd} \times 8.34 \text{ lb/gal} \times \frac{4.7}{100}\right) + \left(5250 \text{ gpd} \times 8.34 \text{ lb/gal} \times \frac{3.5}{100}\right)}{(4750 \text{ gpd} \times 8.34 \text{ lb/gal}) + (5250 \text{ gpd} \times 8.34 \text{ lb/gal})} \times 100 =$$

$$\frac{1862 \text{ lb/d} + 1532 \text{ lb/d}}{39{,}615 + 43{,}785} \times 100 =$$

$$\frac{3394 \text{ lb/d solids}}{83{,}400 \text{ lb/d sludge}} \times 100 = 4.1\%$$

224. $$\frac{\left(8925 \text{ gpd} \times 8.34 \text{ lb/gal} \times \frac{4.0}{100}\right) + \left(11{,}340 \text{ gpd} \times 8.34 \text{ lb/gal} \times \frac{6.6}{100}\right)}{(8925 \text{ gpd} \times 8.34 \text{ lb/gal}) + (11{,}340 \text{ gpd} \times 8.34 \text{ lb/gal})} \times 100 =$$

$$\frac{2977 \text{ lb/d} + 6242 \text{ lb/d}}{74{,}435 \text{ lb/d} + 94{,}576 \text{ lb/d}} \times 100 =$$

$$\frac{9219 \text{ lb/d}}{169{,}011 \text{ lb/d}} \times 100 = 5.5\%$$

225. 3250 lb/d solids × 0.65 = 2113 lb/d VS

226. 4120 gpd × 8.34 lb/gal × 0.07 × 0.70 = 1684 lb/d VS

227. 6600 gpd × 8.34 lb/gal × 0.066 × 0.66 = 2398 lb/d VS

228. 23,650 lb/d sludge × 0.066 × 0.64 = 999 lb/d VS

229. 2560 gpd sludge × 8.34 lb/gal × 0.06 × 0.70 = 897 lb/d VS

230. $$16 = \frac{x \text{ gal seed sludge}}{290{,}000 \text{ gal volume}} \times 100$$

$x$ = 46,400 gal seed sludge

231. $$20 = \frac{x \text{ gal seed sludge}}{0.785 \times 80 \text{ ft} \times 80 \text{ ft} \times 20 \text{ ft} \times 7.48 \text{ gal/ft}^3} \times 100$$

$x$ = 150,318 gal seed sludge

232. $$14 = \frac{x \text{ gal seed sludge}}{0.785 \times 60 \text{ ft} \times 60 \text{ ft} \times 20 \text{ ft} \times 7.48 \text{ gal/ft}^3} \times 100$$

$x$ = 59,188 gal seed sludge

233. $$x = \frac{88{,}350 \text{ gal}}{0.785 \times 70 \text{ ft} \times 70 \text{ ft} \times 22 \text{ ft} \times 7.48 \text{ gal/ft}^3} \times 100$$

$x$ = 14%

234. $x = \frac{3 \text{ lb chemical}}{90 \text{ lb solution}} \times 100$

$x = 3.3\%$ strength

235. $6 \text{ oz} = 0.4 \text{ lb}$

$$x = \frac{0.4 \text{ lb polymer}}{10 \text{ gal} \times 8.34 \text{ lb/gal} + 0.4 \text{ lb}} \times 100$$

$$x = \frac{0.4}{83.8} \times 100$$

$x = 0.5\%$ strength

236. $1.7 = \frac{x \text{ lb polymer}}{(60 \text{ gal})(8.34 \text{ lb/gal}) + x \text{ lb polymer}}$

$$0.017 = \frac{x}{524 + x} \times 100$$

$$(0.017)(524 + x) = x$$

$$8.9 + 0.017\ x = x$$

$$8.9 = x - 0.017\ x$$

$$8.9 = 0.983\ x$$

$$9.1 \text{ lb} = x$$

237. $600 \text{ g} = 1.32 \text{ lb dry polymer}$

$$x = \frac{1.32 \text{ lb polymer}}{9 \text{ gal} \times 8.34 \text{ lb/gal} + 1.32 \text{ lb}} \times 100$$

$$x = \frac{1.32}{75.1 + 1.32} \times 100$$

$$x = 1.7\%$$

238. $1.9 = \frac{x \text{ lb chemical}}{6 \text{ gal} \times 8.34 \text{ lb/gal} + x \text{ lb}}$

$$\frac{1.9}{100} = \frac{x \text{ lb}}{50 \text{ lb} + x \text{ lb}}$$

$$0.019 = \frac{x}{50 \text{ lb} + x \text{ lb}}$$

$$0.019 = 50 \text{ lb} + x = x$$

$$0.95 + 0.019 = x$$

$$0.95 = x - 0.019\ x$$

$$0.95 = 0.981\ x$$

$$0.97 \text{ lb} = x$$

$$0.97 \text{ lb} \times 454 \text{ g/lb} = 440 \text{ g}$$

239. $$\frac{\left(16 \text{ lb solution} \times \frac{10}{100}\right) + \left(110 \text{ lb solution} \times \frac{1}{100}\right)}{16 \text{ lb} + 110 \text{ lb}} \times 100 =$$

$$\frac{(16 \times 0.10) + (110 \times 0.01)}{116} \times 100$$

$$x = \frac{1.6 + 1.1}{116} \times 100$$

$$x = 2.3 \text{ strength}$$

240. $$x = \frac{\left(12 \text{ lb} \times \frac{14}{100}\right) + \left(350 \text{ lb} \times \frac{0.5}{100}\right)}{12 \text{ lb} + 350 \text{ lb}} \times 100$$

$$x = \frac{(12 \times 14) + (350 \times 0.005)}{362} \times 100$$

$$x = \frac{1.7 + 1.8}{362} \times 100$$

$$x = \frac{3.5}{362} \times 100$$

$$x = 0.97 \text{ strength}$$

241. $$x = \frac{\left(22 \text{ lb} \times \frac{12}{100}\right) + \left(440 \text{ lb} \times \frac{0.5}{100}\right)}{22 \text{ lb} + 440 \text{ lb}} \times 100$$

$$x = \frac{2.6 \text{ lb} + 2.2 \text{ lb}}{462 \text{ lb}} \times 100$$

$$x = 1\% \text{ strength}$$

242. 12% solution: 12 gal × 9.9 lb/gal = 119 lb
0.1% solution: 70 gal × 8.34 lb/gal = 584 lb

$$x = \frac{\left(119 \text{ lb} \times \frac{12}{100}\right) + \left(584 \text{ lb} \times \frac{0.1}{100}\right)}{119 \text{ lb} + 584 \text{ lb}}$$

$$x = \frac{14.3 \text{ lb} + 0.58 \text{ lb}}{704 \text{ lb}} \times 100$$

$$x = 2.1 \text{ strength}$$

243. $$\text{bhp} = \frac{600 \times 90 \times 1.03}{3960 \times 0.85}$$

$$= 16.5 \text{ hp}$$

244. $x = \dfrac{8.5 \text{ whp}}{12 \text{ bhp}} \times 100$

$= 0.71 \times 100$

$= 71\%$

245. $x = \dfrac{14 \text{ whp}}{25 \text{ mhp}} \times 100$

$= 0.56 \times 100$

$= 565$

246. $x = \dfrac{12 \text{ kW}}{0.746 \text{ kW/hp}} = 16.09 \text{ hp}$

$= \dfrac{14 \text{ bhp}}{16.09 \text{ mhp}} \times 100 = 87\%$

247. $x = \dfrac{18 \text{ hp}}{20 \text{ hp}} \times 100 = 90\%$

248. $x = \dfrac{38 \text{ hp}}{40 \text{ hp}} \times 100 = 95\%$

249. $88 = \dfrac{x}{22} \times 100$

$x = 19 \text{ hp}$

250. $60 = \dfrac{x}{60} \times 100$

$x = 36 \text{ hp}$

251. $88 = \dfrac{35.5 \text{ hp}}{x} \times 100$

$x = 40 \text{ hp}$

252. $x = \dfrac{222}{240} \times 100$

$x = 93\%$

253. 7400 gpd × 8.34 lb/gal × 0.06 × 0.66 = 2444 lb/d VS

254. $$\frac{\left(2500 \text{ gpd} \times 8.34 \text{ lb/gal} \times \dfrac{4.0}{100}\right) + \left(3270 \text{ gpd} \times 8.34 \text{ lb/gal} \times \dfrac{3.8}{100}\right)}{(2500 \text{ gpd} \times 8.34 \text{ lb/gal}) + (3270 \text{ gpd} \times 8.34 \text{ lb/gal})} \times 100 =$$

$$\frac{834 \text{ lb/d} + 1036 \text{ lb/d}}{20{,}850 \text{ lb/d} + 27{,}272 \text{ lb/d}} \times 100 =$$

$$\frac{1870 \text{ lb/d}}{48{,}122 \text{ lb/d}} \times 100 =$$

3.9% solids

255. $x = \dfrac{3 \text{ lb}}{96 \text{ lb solution}} \times 100$

$= 3.1\%$

256. $21 = \dfrac{x \text{ gal}}{0.785 \times 90 \text{ ft} \times 90 \text{ ft} \times 34 \text{ ft} \times 7.48 \text{ gal/ft}^3} \times 100$

$x = 339{,}590 \text{ gal}$

257. $x = \dfrac{\left[10 \text{ lb} \times (12/100)\right] + \left[500 \text{ lb} \times (0.15/100)\right]}{10 \text{ lb} + 500 \text{ lb}} \times 100$

$= \dfrac{1.2 \text{ lb} + 0.75 \text{ lb}}{510 \text{ lb}} \times 100 = 0.38\%$

258. $x = \dfrac{21.5 \text{ hp}}{26.5 \text{ hp}} \times 100$

$= 81\% \text{ efficiency}$

259. $x = \dfrac{257 \text{ mg/L}}{340 \text{ mg/L}} \times 100$

$= 76\% \text{ efficiency}$

260. $x = \dfrac{\left[8800 \text{ gal} \times 8.34 \text{ lb/gal} \times (4.6/100)\right] + \left[11{,}300 \text{ gpd} \times 8.34 \text{ lb/gal} \times (6.0/100)\right]}{(8800 \text{ gpd} \times 8.34 \text{ lb/gal}) + (11{,}300 \text{ gpd} \times 8.34 \text{ lb/gal})} \times 100$

$= \dfrac{3376 \text{ lb/d} + 5655 \text{ lb/d}}{73{,}392 \text{ lb/d} + 94{,}242 \text{ lb/d}} \times 100$

$= \dfrac{9031 \text{ lb/d}}{167{,}634 \text{ lb/d}} \times 100$

$= 5.4\%$

261. $x = 7300 \text{ gpd} \times 8.34 \text{ lb/gal} \times (6.0/100) \times (70/100)$

$= 2557 \text{ lb/d VS}$

262. $5.8 = \dfrac{x \text{ lb/d solids}}{36{,}100 \text{ lb/d sludge}} \times 100$

$= 2094 \text{ lb/d}$

263. $0.5 = \dfrac{x \text{ lb polymer}}{(70 \text{ gal} \times 8.34 \text{ lb/gal}) + \text{lb}} \times 100$

$0.5 = \dfrac{x \text{ lb}}{584 \text{ lb} + x \text{ lb}} \times 100$

$0.5 \times (584 \text{ lb} + x) = x$

$292 + 0.5\ x = x$

$292 = x - 0.5\ x$

$292 = 0.5\ x$

$x = 584 \text{ lb}$

264. $26 = \frac{x \text{ gal}}{200{,}000 \text{ gal}} \times 100$

$x = 52{,}000$ gal

265. $x = 7100$ lb/d solids $\times$ 0.70

$= 4970$ lb/d VS

266. $x = \frac{[9 \text{ lb} \times (8/100)] + [80 \times (1/100)]}{91 \text{ lb} + 80 \text{ lb}} \times 100$

$= \frac{0.72 + 0.8}{89 \text{ lb}} \times 100 = .90\%$

267. $x = \frac{28 \text{ hp}}{40 \text{ hp}} \times 100 = 70\%$ efficiency

268. $68 = \frac{x \text{ whp}}{80 \text{ hp}} \times 100$

$x = 54$ whp

269. $14.9 \text{ psi} - 9.7 = 5.0 \text{ psi}$

$5.0 \text{ psi} \times 2.31 \text{ ft/psi} = 11.5 \text{ ft}$

270. $62.4 \text{ lb/ft}^3 \times 15 \text{ ft} = \frac{936 \text{ lb/ft}^3}{144 \text{ in.}^2/\text{ft}^2}$

$= 6.5 \text{ lb/in.}^2$ (or psi)

271. $100 \text{ psi} \times 2.31 \text{ ft/psi} = 231 \text{ ft}$

272. (a) $3.14 \times 1^2/4 = 0.785 \text{ ft}^2 = 10 \text{ ft/sec} \times 0.785 \text{ ft}^2 = 7.85 \text{ ft}^3/\text{sec}$

(b) 7.85 cfs × 449 gpm/cfs = 3520 gpm

(c) $\frac{7.85 \text{ cfs}}{1.55 \text{ cfs/MGD}} = 5.06$ MGD

273. 12-in. pipe = $3.14 \times (1 \text{ ft})^2/4 = 0.785 \text{ ft}^2$

6-in. pipe = $3.14 \times (0.5^2/4) = 0.196 \text{ ft}^2 = 0.785 \text{ ft}^2 \times 3 \text{ ft/sec} = 0.196 \text{ ft}^2 \times V_2$

$V_2 = \frac{0.785 \text{ ft}^2 \times 3 \text{ ft/s}}{0.196 \text{ ft}^2} = 12 \text{ ft/s}$

274. Pumping rate (gpm) $= \frac{16{,}400 \text{ gal}}{15 \text{ min}} = 1093$ gpm

275. $0.785 \times 50 \text{ ft} \times 50 \text{ ft} \times 1.5 \text{ ft} = 2944 \text{ ft}^3$

$2944 \text{ ft}^3 \times 7.48 \text{ gal/ft}^3 = 22{,}021$ gal

$\frac{22{,}021 \text{ gal}}{80 \text{ min}} = 275.3$ gpm

276. 9.1 lb/1 gal = 9.1 lb/gal

277. $\frac{66.3 \text{ lb/ft}^3}{7.48 \text{ gal/ft}^3} = 8.9$ lb/gal

278. $\dfrac{55\text{ lb/ft}^3}{62.4\text{ lb/ft}^3} = 0.89$

279. 150 lb – 85 lb = 65 lb

150 lb/65 lb = 2.3

280. 8.34 lb/gal × 0.94 = 7.84 lb/gal

1455 gal × 7.84 lb/gal = 11,407 lb

281. 1.4 × 8.34 lb/gal = 11.7 lb/gal

282. $\dfrac{9.1\text{ lb}}{8.34\text{ lb/gal}} = 1.1$

283. 90 ft × 0.433 psi/ft = 39 psi

284. $\dfrac{22\text{ psi}}{0.433\text{ psi}} = 51\text{ ft}$

285. $\dfrac{85\text{ lb}}{36\text{ in.} \times 24\text{ in.}} =$

$\dfrac{85\text{ lb}}{864\text{ in.}^2} = 0.1\text{ lb/in.}^2$

286. 2.8 lb/in.$^2$ × 4 = 11.2 lb/in.$^2$

287. 8 ft × 62.4 lb/ft$^3$ = 499.2 lb/ft$^2$

288. $\dfrac{9\text{ ft}}{2.31\text{ ft/psi}} = 3.9\text{ psi}$

289. $\dfrac{5\text{ ft}}{2.31\text{ ft/psi}} = 2.2\text{ psi}$

2.2 psi × 1.4 = 3.1 psi

290. $\dfrac{12\text{ ft}}{2.31\text{ ft/psi}} = 5.2\text{ psi}$

5.2 psi × 360 in. × 168 in. = 314,496 lb

291. 5 × 62.4 lb/ft$^2$ = 312 lb/ft$^2$

312 lb/ft$^2$ × 30 ft × 12 ft = 112,320 lb

292. 2/3 × 10 ft = 6.7 ft

293. $\dfrac{60\text{ lb}}{0.785 \times 0.67\text{ ft} \times 0.67\text{ ft}} = 171\text{ lb/ft}^2$

171 lb/ft$^2$ × 0.785 × 2.5 ft × 2.5 ft = 839 lb

294. 30 psi gauge + 14.7 psi atmosphere = 46.7 psi absolute

295. 215 ft – 118 ft = 97 ft

296. 72.3 psi × 2.31 ft/psi = 167 ft

297. 320 ft – 241 ft = 79 ft

298. 780 ft – 624 ft = 156 ft

TDH = 156 ft + 18 ft = 174 ft

299. $\text{HP} = \dfrac{25\text{ ft} \times 1600\text{ gpm} \times 8.34\text{ lb/gal}}{33{,}000\text{ ft-lb/min/hp}} = 10.1\text{ hp}$

300. 25 mhp × (80/100) = 20 bhp

whp = 20 bhp × (80/100) = 16 whp

301. $\dfrac{40 \text{ whp}}{80/100} = 50 \text{ bhp}$

302. $\text{hp} = \dfrac{70 \text{ ft} \times 700 \text{ gpm} \times 8.34 \text{ lb/gal} \times 1.3 \text{ specific gravity}}{33{,}000 \text{ ft-lb/min/hp}} = 16.1 \text{ whp}$

303. 50 hp × 746 W/hp = 37,300 W

$\dfrac{37{,}300 \text{ W}}{1000 \text{ W/kW}} = 37.3 \text{ kW}$

304. 80 mhp × 746 W/hp = 59,680 W

$\dfrac{59{,}680 \text{ W}}{1000 \text{ W/kW}} = 59.7 \text{ kW}$

59.7 kW × 148 hr = 8835.6 kWh

8835.6 kWh × 0.0591/kWh = $525.80

305. $\dfrac{10 \text{ ft} \times 8 \text{ ft} \times 2.1 \text{ ft} \times 7.48 \text{ gal/ft}^3}{5 \text{ min}} = 251 \text{ gpm}$

306. $\dfrac{55 \text{ gal}}{0.53 \text{ min}} = 104 \text{ gpm}$

307. $\dfrac{9 \text{ ft} \times 12 \text{ ft} \times 0.25 \text{ ft} \times 7.48 \text{ gal/ft}^3}{5 \text{ min}} = 40 \text{ gpm}$

500 gpm – 40 gpm = 460 gpm

308. $\dfrac{0.80 \text{ gal}}{\text{stroke}} \times \dfrac{30 \text{ strokes}}{\text{min}} = 24 \text{ gpm}$

309. (0.785 × 0.67 ft × 0.67 ft × 0.25 ft × 7.48 gal/ft$^3$) × 35 strokes/min = 23.1 gpm

23.1 gpm × 140 min/d = 3234 gpd

310. 22 psi × 2.31 ft/psi = 51 ft

311. 62.4 lb/ft$^3$ × 16 ft = 998.4 lb/ft$^3$

312. TDH = 30 × (2.31/1.03) = 67 ft

$\text{bhp} = \dfrac{800 \times 67 \times 1.03}{3960 \times 0.70} = 19.9 \text{ hp}$

313. (9.0 whp/10 bhp) × 100 = 90%

314. $\dfrac{68 \text{ lb/ft}^3}{7.48 \text{ ft}^3} = 9.1 \text{ lb/gal}$

315. $\dfrac{14 \text{ ft} \times 10 \text{ ft} \times 1.5 \text{ ft} \times 7.48 \text{ gal/ft}^3}{5 \text{ min}} = 314 \text{ gpm}$

316. (0.785 × 0.5 ft × 0.5 ft × 0.25 ft × 7.48 gal/ft$^3$) × 60 stroke/min = 22 gpm

317. $\dfrac{60 \text{ ft} \times 800 \text{ gpm} \times 8.34 \text{ lb/gal}}{33{,}000 \text{ ft-lb/min/hp}} = 12.1 \text{ hp}$

318. (0.785 ×0.67 ft × 0.67 ft × 0.29 × 7.48 gal/ft$^3$) × 55 strokes/min = 42 gpm

42 gpm × 120 min/d = 5040 gpd

319. 1.5 × 8.34 lb/gal = 12.5 lb/gal

320. 848 ft – 766 ft = 82 ft

TDH = 82 ft + 10 ft = 92 ft

321. $5.5 \text{ ft} \times 62.4 \text{ lb/ft}^3 = 343 \text{ lb/ft}^2$

$343 \text{ lb/ft}^2 \times 16 \text{ ft} \times 11 \text{ ft} = 60{,}368 \text{ lb}$

322. $60 \text{ hp} \times (92/100) = 55 \text{ bhp}$

$55 \text{ hp} \times (88/100) = 48 \text{ whp}$

323. $I = 3/6$

$I = 0.5 \text{ A}$

324. $I = 6/6$

$I = 1 \text{ A}$

325. $I = 3/12$

$I = 0.25 \text{ A}$

326. $E = 2.5 \times 25 = 62.5 \text{ V}$

327. $220 \text{ V}/10 \text{ A} = 22\ \Omega$

328. $120 \text{ V}/0.5\text{A} = 240\ \Omega$

329. $P = (0.25 \text{ A})^2 \times 200\ \Omega = 0.0625 \times 200 = 12.5 \text{ W}$

330. $P = 220 \text{ V} \times 30 \text{ A} = 6600 \text{ W} = 6.6 \text{ kW}$

331. $$\frac{450^2 \text{ V}}{30{,}000\ \Omega} = \frac{202{,}500 \text{ V}}{30{,}000\ \Omega} = 6.75 \text{ W}$$

332. $12 \times 4 = 48 \text{ kW}$

333. $R_t = 10\ \Omega + 12\ \Omega + 25\ \Omega = 47\ \Omega$

334. $R_3 = 50\ \Omega - 12\ \Omega - 12\ \Omega = 50\ \Omega - 24\ \Omega = 26\ \Omega$

335. $E_1 = 10 \times 2.4 = 25 \text{ V}$

$E_2 = 20 \times 2.5 = 50 \text{ V}$

$E_3 = 40 \times 2.5 = 100 \text{ V}$

$E_t = 25 \text{ V} + 50 \text{ V} + 100 \text{ V} = 175 \text{ V}$

336. $R_t = 5\ \Omega + 15\ \Omega + 20\ \Omega = 40\ \Omega$

$I = 120/40 = 3 \text{ A}$

$P_1 = 3^2 \times 5 = 45 \text{ W}$

$P_2 = 3^2 \times 15 = 135 \text{ W}$

$P_3 = 3^2 \times 20 = 180 \text{ W}$

$P_t = 45 + 135 + 180 = 360 \text{ W}$

$P_t = 120 \text{ V} \times 3 \text{ A} = 360 \text{ W}$

337. $ER_2 = 4.0 \text{ ma} \times 40{,}000\ \Omega$

$ER_2 = 4.0 \times 10^{-3} \times 40\ x\ 10^3 = 4.0 \times 40 = 160 \text{ V}$

E = 160 V

338. 2 A + 2 A + 1 A = 5 A

339. $50/5 = 10\ \Omega$

340. $$\frac{20 \times 30}{20 + 30} = 12\ \Omega$$

341. $80.81^2 = 6530 \text{ circular mil} = 0.785 \times 6530 = 5126 \text{ mil}^2$

342. $2000\ (5 \times 10^{-3}) = 10 \text{ At}$

## WATER TREATMENT CALCULATIONS (PROBLEMS 1 TO 457)

1. 98 ft – 91 ft = 7 ft drawdown
2. 125 ft – 110 ft = 15 ft drawdown
3. 161 ft – 144 ft = 17 ft drawdown
4. 3.7 psi × 2.31 ft/psi = 8.5 ft water depth in sounding line
   112 ft – 8.5 ft = 103.5 ft
   103.5 ft – 86 ft = 17.5 ft
5. 4.6 psi × 2.31 ft/psi = 10.6 ft water depth in sounding line
   150 ft – 10.6 ft = 139.4 ft
   171 ft – 139.4 ft = 31.4
6. 300/20 = 15 gpm/ft drawdown
7. 420 gal/5 min = 84 gpm
8. 810 gal/5 min = 162 gpm
9. 856 gal/5 min = 171 gpm
   171 gpm × 60 min/hr = 10,260 gph
10. $$\frac{0.785 \times 1 \text{ ft} \times 1 \text{ ft} \times 12 \text{ ft} \times 7.48 \text{ gal/ft}^3 \times 12 \text{ round trips}}{5 \text{ min}} = 169 \text{ gpm}$$
11. 750 gal/5 min = 150 gpm
    150 gpm × 60 min/hr = 9000 gph
    9000 gph × 10 hr/d = 90,000 gal/d
12. 200 gpm/28 ft = 7.1 gpm/ft
13. 620 gpm/21 ft = 29.5 gpm/ft
14. 1100 gpm/41.3 ft = 26.6 gpm/ft
15. $$\frac{x \text{ gpm}}{42.8 \text{ ft}} = 33.4 \text{ fpm/ft}$$
    $x$ = 33.4 × 42.8 = 1430 gpm
16. 0.785 × 0.5 ft × 0.5 ft × 140 ft × 7.48 gal/ft$^3$ = 206 gal
    40 mg/L × 0.000206 MG × 8.34 lb/gal = 0.07 lb chlorine
17. 0.785 × 1 ft × 1 ft × 109 ft × 7.48 gal/ft$^3$ = 640 gal
    40 mg/L × 0.000640 MG × 8.34 lb/gal = 0.21 lb chlorine
18. 0.785 × 1 ft × 1 ft × 109 ft × 7.48 gal/ft$^3$ = 633 gal
    0.785 × 0.67 ft × 0.67 ft × 40 ft × 7.48 gal/ft$^3$ = 105 gal
    633 + 105 gal = 738 gal
    110 mg/L × 0.000738 gal × 8.34 lb/gal = 0.68 lb chlorine
19. $x$ mg/L × 0.000540 gal × 8.34 lb/gal = 0.48 lb
    $$x = \frac{0.48}{0.000540 \times 8.34} = 107 \text{ mg/L}$$
20. $$\frac{0.09 \text{ lb chlorine}}{5.25/100} = 1.5 \text{ lb}$$
    $$\frac{1.5 \text{ lb}}{8.34 \text{ lb/gal}} = 0.18 \text{ gal}$$
    0.18 gal × 128 fl oz/gal = 23 fl oz

21. $0.785 \times 0.5 \text{ ft} \times 0.5 \text{ ft} \times 120 \text{ ft} \times 7.48 \text{ gal/ft}^3 = 176 \text{ gal}$

$$\frac{50 \text{ mg/L chlorine} \times 0.000176 \text{ MG} \times 8.34 \text{ lb/gal}}{65/100} = 0.1 \text{ calcium hypochlorite}$$

$0.1 \text{ lb} \times 16 \text{ oz/lb} = 1.6 \text{ oz calcium hypochlorite}$

22. $0.785 \times 1.5 \text{ ft} \times 1.5 \text{ ft} \times 105 \text{ ft} \times 748 \text{ gal/ft}^3 = 1387 \text{ gal}$

$$\frac{100 \text{ mg/L} \times 0.001387 \text{ MG} \times 8.34 \text{ lb/gal}}{25/100} = 4.6 \text{ lb chloride of lime}$$

23. $$\frac{60 \text{ mg/L} \times 0.000240 \text{ MG} \times 8.34 \text{ lb/gal}}{5.25/100} = 2.3 \text{ lb}$$

$$\frac{2.3 \text{ lb}}{8.34 \text{ lb/gal}} = 0.3 \text{ gal}$$

$0.3 \text{ gal} \times 128 \text{ fl oz/gal} = 38.4 \text{ fl oz sodium hypochlorite}$

24. $4.0 \text{ psi} \times 2.31 \text{ ft/psi} = 9.2 \text{ ft}$

25. $(94 \text{ ft} + 24 \text{ ft}) + (3.6 \text{ psi} \times 2.31 \text{ ft/psi}) = 118 \text{ ft} + 8.3 \text{ ft} = 126.3 \text{ ft}$

26. $4.2 \text{ psi} \times 2.31 \text{ ft/psi} = 9.7 \text{ ft}$

$180 \text{ ft} + 9.7 \text{ ft} = 189.7 \text{ ft}$

$$\text{whp} = \frac{189.7 \text{ ft} \times 800 \text{ gpm}}{3960} = 38.3 \text{ whp}$$

27. $4.4 \text{ psi} \times 2.31 \text{ ft/psi} = 10.2 \text{ ft}$

Field head = $200 \text{ ft} + 10.2 \text{ ft} = 210.2 \text{ ft}$

$$\text{whp} = \frac{210.2 \text{ ft} \times 1000 \text{ gpm}}{3960} = 53 \text{ whp}$$

28. $$\frac{184 \text{ ft} \times 700 \text{ gpm}}{3960 \times (83/100)} = 39 \text{ bowl bhp}$$

29. Shaft friction loss = 0.67

$$\frac{0.67 \text{ hp loss}}{100 \text{ ft}} \times 181 \text{ ft} = 1.2 \text{ hp loss}$$

Field hp = $59.5 \text{ bhp} + 1.2 \text{ hp} = 60.7 \text{ bhp}$

30. $$\text{mhp} = \frac{\text{total bhp}}{\text{motor efficiency}/100}$$

$$\frac{58.3 \text{ bhp} + 0.5 \text{ hp}}{90/100} = 65.3 \text{ mhp}$$

31. $$\frac{45 \text{ hp}}{56.4 \text{ hp}} \times 100 = 80\%$$

32. $$\frac{55.7 \text{ bhp}}{90/100} = 62 \text{ hp input}$$

$$\frac{43.5 \text{ whp}}{62 \text{ input hp}} = 70\%$$

33. $400 \text{ ft} \times 110 \text{ ft} \times 14 \text{ ft} \times 7.48 \text{ gal/ft}^3 = 4{,}607{,}680 \text{ gal}$

34. $400 \text{ ft} \times 110 \text{ ft} \times 30 \text{ ft} \times 0.4 \text{ average depth} \times 7.48 \text{ gal/ft}^3 = 3{,}949{,}440 \text{ gal}$

35. $\dfrac{200 \text{ ft} \times 80 \text{ ft} \times 12 \text{ ft}}{43{,}560 \text{ ft}^3/\text{acre-ft}} = 4.4 \text{ acre-ft}$

36. $\dfrac{320 \text{ ft} \times 170 \text{ ft} \times 16 \text{ ft} \times 0.4}{43{,}560 \text{ ft}^3/\text{acre-ft}} = 80 \text{ acre-ft}$

37. $\dfrac{0.5 \text{ mg/L chlorine} \times 20 \text{ MG} \times 8.34 \text{ lb/gal}}{25/100} = 334 \text{ lb copper sulfate}$

38. 62 acre-ft × 43,560 ft$^3$/acre-ft × 7.48 gal/ft$^3$ = 20,201,385 gal

$\dfrac{0.5 \text{ mg/L} \times 20.2 \text{ MG} \times 8.34 \text{ lb/gal}}{0.25} = 337 \text{ lb copper sulfate}$

39. $\dfrac{1.1 \text{ lb } CuSO_4}{1 \text{ acre-ft}} \times 38 \text{ acre-ft} = 41.8 \text{ lb copper sulfate}$

40. $\text{Volume (acre-ft)} = \dfrac{250 \text{ ft} \times 75 \text{ ft} \times 10 \text{ ft}}{43{,}560 \text{ ft}^3/\text{acre-ft}} = 4.3 \text{ acre-ft}$

$\dfrac{0.8 \text{ lb } CuSO_4}{1 \text{ acre-ft}} \times 4.3 \text{ acre-ft} = 3.14 \text{ lb copper sulfate}$

41. $\text{Volume (acre-ft)} = \dfrac{500 \text{ ft} \times 100 \text{ ft}}{43{,}560 \text{ ft}^2/\text{acre}} = 1.1 \text{ acre}$

$\dfrac{5.1 \text{ lb } CuSO_4}{1} \times 1.1 \text{ acre} = 5.9 \text{ lb copper sulfate}$

42. 131.9 ft – 93.5 ft = 38.4 ft

43. $\dfrac{707 \text{ gal}}{5 \text{ min}} = 141 \text{ gpm}$

141 gpm × 60 min/hr = 8460 gph

44. $\dfrac{0.785 \times 1 \text{ ft} \times 1 \text{ ft} \times 12 \text{ ft} \times 7.48 \text{ gal/ft}^3 \times 8 \text{ round trips}}{5 \text{ gpm}} = 113 \text{ gpm}$

45. 3.5 psi × 2.31 ft/psi = 8.1 ft water depth in sounding line

167 ft – 8.1 ft = 158.9 ft pumping water level

Drawdown (ft) = 158.9 ft – 141 ft = 17.9 ft drawdown

46. $\dfrac{610 \text{ gpm}}{28 \text{ ft drawdown}} = 21.8 \text{ gpm/ft}$

47. 0.785 × 0.5 ft × 0.5 ft × 150 ft × 7.48 gal/ft$^3$ = 220 gal

Chlorine (lb) required: 55 mg/L × 0.000220 MG × 8.34 lb/gal = 0.10 lb chlorine

48. 780 gal/5 min = 156 gpm

156 gal/min × 60 min/hr × 8 hr/d = 74,880 gal/d

49. $x$ mg/L × 0.000610 MG × 8.34 lb/gal = 0.47 lb

$x = \dfrac{0.47}{0.000610 \times 8.34} = 92.3 \text{ mg/L}$

50. 0.785 × 1 ft × 1 ft × 89 × 7.48 gal/ft$^3$ = 523 gal

0.785 × 0.67 × 0.67 × 45 ft × 7.48 gal/ft$^3$ = 119 gal

523 gal + 119 gal = 642 gal

$100\ \text{mg/L} \times 0.000642\ \text{MG} \times 8.34\ \text{lb/gal} = 0.54\ \text{lb chlorine}$

51. $$\frac{0.3\ \text{lb chlorine}}{5.25/100} = 5.7\ \text{lb}$$

$$\frac{5.7\ \text{lb}}{8.34\ \text{lb/gal}} = 0.68\ \text{gal}$$

$$0.68\ \text{gal} \times 128\ \text{fl oz/gal} = 87\ \text{fl oz}$$

52. $4.5\ \text{psi} \times 2.31\ \text{psi} = 10.4\ \text{ft}$
53. $3.6\ \text{psi} \times 2.31\ \text{ft/psi} = 8.3\ \text{ft}$, $95\ \text{ft} + 25\ \text{ft} + 8.3\ \text{ft} = 128.3\ \text{ft}$ field head
54. Field head = $191\ \text{ft} + (4.1\ \text{psi} \times 2.31\ \text{ft/psi})$

$191\ \text{ft} + 9.5\ \text{ft} = 200.5\ \text{ft}$

$$\text{whp} = \frac{200.5\ \text{ft} \times 850\ \text{gpm}}{3960} = 43\ \text{whp}$$

55. $$\frac{175\ \text{ft} \times 800\ \text{gpm}}{3960 \times 0.80} = 44.2\ \text{whp}$$

56. $$\frac{47.8\ \text{bhp} + 0.8\ \text{hp}}{0.90} = 54\ \text{hp input}$$

57. $$\frac{45.6\ \text{hp}}{57.4\ \text{bhp}} \times 100 = 79.8\%$$

58. $$\frac{54.7\ \text{bhp}}{0.90} = 61\ \text{hp input}$$

$$\text{Overall efficiency } (\%) = \frac{44.6\ \text{whp}}{61\ \text{input hp}} = 73\%$$

59. $53\ \text{acre-ft} \times 43{,}560\ \text{ft}^3/\text{acre ft} = 2{,}308{,}680\ \text{ft}^3$

$2{,}308{,}680\ \text{ft}^3 \times 7.48\ \text{gal/ft}^3 = 17{,}268{,}926\ \text{gal}$

$$\frac{0.5\ \text{mg/L} \times 17.2\ \text{MG} \times 8.34\ \text{lb/gal}}{0.25} = 287\ \text{lb copper sulfate}$$

60. $$\text{Area (acres)} = \frac{440\ \text{ft} \times 140\ \text{ft}}{43{,}560\ \text{ft}^2/\text{acre}} = 1.4\ \text{acre}$$

$5.5\ \text{lb copper sulfate} \times 1.4\ \text{acre} = 7.7\ \text{lb copper sulfate/acre}$

61. Volume (gal) = $4\ \text{ft} \times 5\ \text{ft} \times 3\ \text{ft} \times 7.48\ \text{gal/ft}^3 = 449\ \text{gal}$
62. Volume (gal) = $50\ \text{ft} \times 20\ \text{ft} \times 8\ \text{ft} \times 7.48\ \text{gal/ft}^3 = 59{,}840\ \text{gal}$
63. Volume (gal) = $40\ \text{ft} \times 16\ \text{ft} \times 8\ \text{ft} \times 7.48\ \text{gal/ft}^3 = 38{,}298\ \text{gal}$
64. $42\ \text{in.} \div 12\ \text{in./ft} = 3.5\ \text{ft}$

Volume (gal) = $5\ \text{ft} \times 5\ \text{ft} \times 3.5\ \text{ft} \times 7.48\ \text{gal/ton}^3 = 655\ \text{gal}$

65. $2\ \text{in.} \div 12\ \text{in./ft} = 0.17\ \text{ft}$

Volume (gal) = $40\ \text{ft} \times 25\ \text{ft} \times 9.17\ \text{ft} \times 7.48\ \text{gal/ft}^3 = 68{,}592\ \text{gal}$

66. $$\frac{3{,}625{,}000\ \text{gpd}}{1440\ \text{min/d}} = 2517\ \text{gpm}$$

$$\frac{60\ \text{ft} \times 25\ \text{ft} \times 9\ \text{ft} \times 7.48\ \text{gal/ft}^3}{2517\ \text{gpm}} = 40.1\ \text{min}$$

67. $\frac{2,800,000 \text{ gpd}}{1440 \text{ min/d}} = 1944 \text{ gpm}$

$$\text{Detention time (min)} = \frac{50 \text{ ft} \times 20 \text{ ft} \times 8 \text{ ft} \times 7.48 \text{ gal/ft}^3}{1944 \text{ gpm}} = 30.8 \text{ min}$$

68. $\frac{9,000,000 \text{ gpd}}{1440 \text{ min/d} \times \text{sec/min}} = 104.2 \text{ gps}$

$$\text{Detention time (sec)} = \frac{6 \text{ ft} \times 5 \text{ ft} \times 5 \text{ ft} \times 7.48 \text{ gal/ft}^3}{104.2 \text{ gps}} = 10.8 \text{ sec}$$

69. $\frac{2,250,000 \text{ gpd}}{1440 \text{ min/d}} = 1563 \text{ gpm}$

$$\text{Detention time (sec)} = \frac{50 \text{ ft} \times 20 \text{ ft} \times 10 \text{ ft} \times 7.48 \text{ gal/ft}^3}{1563 \text{ gpm}} = 47.9 \text{ min}$$

70. $\frac{3,250,000 \text{ gpd}}{1440 \text{ min/d} \times 60 \text{ sec/min}} = 37.6 \text{ gps}$

$$\text{Detention time (sec)} = \frac{4 \text{ ft} \times 4 \text{ ft} \times 3.5 \text{ ft} \times 7.48 \text{ gal/ft}^3}{37.6 \text{ gpm}} = 11.1 \text{ sec}$$

71. 10 mg/L × 3.45 MGD × 8.34 lb/gal = 288 lb/d
72. 12 mg/L × 1.660 MGD × 8.34 lb/gal = 166 lb/d
73. 10 mg/L × 2.66 MGD × 8.34 lb/gal = 222 lb/d
74. 9 mg/L × 0.94 MGD × 8.34 lb/gal = 71 lb/d
75. 12 mg/L × 4.10 MGD × 8.34 lb/gal = 410 lb/d
76. 7 mg/L × 1.66 MGD × 8.34 lb/gal = 97 lb/d dry alum

$$\frac{97 \text{ lb/d dry alum}}{5.24 \text{ lb alum/gal solution}} = 18.5 \text{ gpd alum solution}$$

77. 12 mg/L × 3.43 MGD × 8.34 lb/gal = 550,000 mg/L × $x$ MGD × 8.34 lb/gal

$$\frac{12 \text{ mg/L} \times 3.43 \times 8.34}{550,000 \times 8.34} = x \text{ MGD}$$

$x$ = 0.0000748 MGD

gpd = 74.8 gpd alum solution

78. 10 mg/L × 4.13 MGD × 8.34 lb/gal = 344 lb/d dry alum

$$\frac{344 \text{ lb/d dry alum}}{5.40 \text{ lb alum/gal solution}} = 64 \text{ gpd solution}$$

79. 11 mg/L × 0.88 MGD × 8.34 lb/gal = 550,000 mg/L × $x$ MGD × 8.34 lb/gal

$$\frac{11 \times 0.88 \times 8.34}{550,000 \times 8.34} = x \text{ MGD}$$

0.0000176 MGD = $x$ = 17.6 gpd alum solution

80. $\frac{640 \text{ mg alum}}{1 \text{ mL solution}} \times \frac{1000}{1000} = \frac{640,000 \text{ mg alum}}{1000 \text{ mL}} = 640,000 \text{ mg/L}$

10 mg/L × 1.85 MGD × 8.34 lb/gal = 640,000 mg/L × $x$ MGD × 8.34 lb/gal

$$\frac{10 \times 1.85 \text{ MGD} \times 8.34}{640,000 \times 8.34} = x \text{ MGD}$$

0.0000289 MGD = 28.9 gpd

81. $$\frac{40 \text{ gpd} \times 3785 \text{ mL/gal}}{1440 \text{ min/d}} = 105 \text{ mL/min}$$

82. $$\frac{34.2 \text{ gpd} \times 3785 \text{ mL/gal}}{1440 \text{ min/d}} = 90 \text{ mL/min}$$

83. 10 mg/L × 2.88 × 8.34 lb/gal = 550,000 mg/L × $x$ MGD × 8.34 lb/gal

$$\frac{10 \times 2.88 \text{ MGD} \times 8.34}{550,000 \times 8.34} = x \text{ MGD}$$

0.0000523 MGD = 52.4 gpd

$$\frac{52.4 \times 3785 \text{ mL/gal}}{1440 \text{ min/d}} = 138 \text{ mL/min}$$

84. 6 mg/L × 282 MGD × 8.34 lb/gal = (550,000 mg/L × $x$ MGD × 8.34 lb/gal)

$$\frac{6 \times 2.82 \times 8.34}{550,000 \times 8.34} = x \text{ MGD}$$

0.0000307 MGD = 30.7 gpd = $x$,

$$\frac{30.7 \text{ gpd} \times 3785 \text{ mL/gal}}{1440 \text{ min/d}} = 80.7 \text{ mL/min}$$

85. $$\frac{10 \text{ mg/L} \times 3.45 \text{ MGD} \times 8.34 \text{ lb/gal}}{5.40 \text{ alum/gal solution}} = 53.3 \text{ mL/min}$$

$$\frac{53.3 \text{ gpd} \times 3785 \text{ mL/gal}}{1440 \text{ min/d}} = 141 \text{ mL/min}$$

86. 140 g = (0.0022 lb × 140) = 0.31 lb dry polymer

$$\frac{0.31 \text{ lb}}{(16 \text{ gal} \times 8.34 \text{ lb/gal}) + 0.31 \text{ lb}} \times 100 = 0.23\%$$

87. 22 oz ÷ 16 oz/lb = 1.38 lb dry polymer

$$\frac{1.38 \text{ lb}}{(24 \text{ gal} \times 8.34 \text{ lb/gal}) + 1.38 \text{ lb}} \times 100 = 0.68\%$$

88. $$\frac{2.1 \text{ lb } (100)}{(x \text{ gal} \times 8.34 \text{ lb/gal}) + 2.1 \text{ lb}} = 0.8$$

$$\frac{210}{8.34x + 2.1} = 0.8$$

210 = (0.8 × 8.34$x$) + 2.1

210 = 6.7$x$ + 1.7

208.3 = 6.7$x$

$x$ = 31 gal

89. 0.11 $x$ = 0.005 × 60

$$x = \frac{0.005 \times 160}{0.11}$$

$x$ = 7.27 lb liquid polymer

90. 1.3 × 8.34 lb/gal = 10.8 lb/gal

(8/100) × $x$ gal liquid polymer × 10.8 lb/gal = (0.2/100 × 50 gal × 8.34 lb/gal)

0.08 × $x$ × 10.8 = 0.002 × 50 × 8.34

$$x = \frac{0.002 \times 50 \times 8.34}{0.09 \times 10.8}$$

$x$ = 0.86 gal liquid polymer

91. (11/100) × $x$ gal × 10.1 lb/gal = (0.8/100) × 80 gal × 8.34 lb/gal

0.11 × $x$ × 10.1 = 0.008 × 80 × 8.34

$$x = \frac{0.008 \times 80 \times 8.34}{0.11 \times 10.1}$$

$x$ = 4.9 gal liquid polymer

92. $$\frac{\left[(10/100) \times 32 \text{ lb}\right] + \left[(0.5/100) \times 66 \text{ lb}\right]}{32 \text{ lb} + 66 \text{ lb}} \times 100 =$$

$$\frac{3.2 \text{ lb} + 0.33 \text{ lb}}{98 \text{ lb}} \times 100 = 3.6\%$$

93. $$\frac{\left[(15/100) \times 5 \text{ gal} \times 11.2 \text{ lb/gal}\right] + \left[(.20/100) \times 40 \text{ gal} \times 8.34 \text{ lb/gal}\right]}{(5 \text{ gal} \times 11.2 \text{ lb/gal}) + (40 \text{ gal} \times 8.34 \text{ lb/gal})} \times 100$$

$$\frac{8.4 \text{ lb} + 0.67 \text{ lb}}{56 \text{ lb} + 334 \text{ lb}} \times 100$$

$$\frac{9.1 \text{ lb}}{390 \text{ lb}} \times 100 = 2.3\% \text{ strength}$$

94. $$\frac{\left[(12/100) \times 12 \text{ gal} \times 10.5 \text{ lb/gal}\right] + \left[(0.75/100) \times 50 \text{ gal} \times 8.40/\text{gal}\right]}{(12 \text{ gal} \times 10.5 \text{ lb/gal}) + (40 \text{ gal} \times 8.40 \text{ lb/gal})} \times 100 =$$

$$\frac{15.1 \text{ lb} + 3.2 \text{ lb}}{126 \text{ lb} + 336 \text{ lb}}$$

$$\frac{18.3 \text{ lb}}{458 \text{ lb}} \times 100 = 4.0\% \text{ strength}$$

95. $$\frac{2.3 \text{ lb}}{30 \text{ min}} = 0.08 \text{ lb/min}$$

0.08 lb/min × 1440 min/d = 115.2 lb/d

96. $$\frac{42 \text{ oz}}{16 \text{ oz lb}} = 2.61 \text{ lb}$$

$$\frac{2.6 \text{ lb}}{45 \text{ min}} = 0.06 \text{ lb/min}$$

0.06 lb/min × 1440 min/d = 86.4 lb/d

97. $\dfrac{14\text{ oz}}{16\text{ oz/lb}} = 0.88\text{ lb containers}$

$2.4\text{ lb chemical} + \text{container} - 0.88\text{ lb container} = 1.52\text{ lb chemical}$

$\dfrac{1.52\text{ lb chemical}}{30\text{ min}} = 0.051\text{ lb/min}$

$0.051\text{ lb/min} \times 1440\text{ min/d} = 73\text{ lb/d}$

98. $2.8\text{ lb container} + \text{chemical} - 0.6\text{ lb container} = 2.2\text{ lb chemical}$

$\dfrac{2.2\text{ lb chemical}}{30\text{ min}} = 0.073\text{ lb/min}$

$0.073\text{ lb/min} \times 1440\text{ min/d} = 105\text{ lb/d}$

99. $x\text{ mg/L} \times 1.92\text{ MGD} \times 8.34\text{ lb/gal} = 42\text{ lb polymer}$

$x = \dfrac{42}{1.92 \times 8.34} = 2.6\text{ mg/L}$

100. $16{,}000\text{ mg/L} \times 0.000070\text{ MGD} \times 8.34\text{ lb/gal} = 9.3\text{ lb/d}$

101. $\dfrac{590\text{ mL}}{5\text{ min}} = 118\text{ mL/min}$

$118\text{ mL/min} \times \dfrac{1\text{ gal}}{3785\text{ mL}} \times 1440\text{ min/d} = 44.9\text{ gpd}$

$12{,}000\text{ mg/L} \times 0.0000449\text{ MGD} \times 8.34\text{ lb/gal} \times 1.09\text{ specific gravity} = 4.9\text{ lb/d}$

102. $\dfrac{725\text{ mL}}{5\text{ min}} = 145\text{ mL/min}$

$145\text{ mL/min} \times \dfrac{1\text{ gal}}{3785\text{ mL}} \times 1440\text{ min/d} = 55\text{ gpd}$

$12{,}000\text{ mg/L} \times 0.000055\text{ MGD} \times 8.34\text{ lb/d} = 5.5\text{ lb/d}$

103. $\dfrac{950\text{ mL}}{5\text{ min}} = 190\text{ mL/min}$

$190\text{ mL/min} \times \dfrac{1\text{ gal}}{3785\text{ mL}} \times 1440\text{ min/d} = 72.3\text{ gpd}$

$14{,}000\text{ mg/L} \times 0.0000723\text{ MGD} \times 8.34\text{ lb/gal} = 8.4\text{ lb/d}$

104. $\dfrac{1730\text{ mL}}{10\text{ min}} = 173\text{ mL/min}$

$173\text{ mL/min} \times \dfrac{1\text{ gal}}{3785\text{ mL}} \times 1440\text{ min/d} = 65.8\text{ gpd}$

$19{,}000\text{ mg/L} \times 0.0000658\text{ MGD} \times 8.34\text{ lb/gal} \times 1.09\text{ specific gravity} = 11.4\text{ lb/d}$

105. $4\text{ in.} \div 12\text{ in./ft} = 0.3\text{ ft}$

$\dfrac{0.785 \times 4\text{ ft} \times 4\text{ ft} \times 0.3\text{ ft} \times 7.48\text{ gal/ft}^3}{5\text{ min}} = 5.6\text{ gpm}$

106. $4\text{ in.} \div 12\text{ in./ft} = 0.3\text{ ft}$

$\dfrac{0.785 \times 4\text{ ft} \times 4\text{ ft} \times 0.3\text{ ft} \times 7.48\text{ gal/ft}^3}{15\text{ min}} = 1.9\text{ gpm}$

107. 3 in. ÷ 12 in./ft = 0.25 ft

$$\frac{0.785 \times 3 \text{ ft} \times 3 \text{ ft} \times 0.25 \text{ ft} \times 7.48 \text{ gal/ft}^3}{10 \text{ min}} = 1.32 \text{ gpm}$$

1.32 gpm × 1440 min/d = 1901 gpd

108. 2 in. ÷ 12 in./ft = 0.17 ft

$$\frac{0.785 \times 3 \text{ ft} \times 3 \text{ ft} \times 0.17 \text{ ft} \times 7.48 \text{ gal/ft}^3}{15 \text{ min}} = 0.6 \text{ gpm}$$

0.6 gpm × 1440 min/d = 864 gpd

12,000 mg/L × 0.000864 MGD × 8.34 lb/gal = 86.5 lb/d

109. $$\frac{0.785 \times 4 \text{ ft} \times 4 \text{ ft} \times 0.17 \text{ ft} \times 7.48 \text{ gal/ft}^3}{30 \text{ min}} = 0.53 \text{ gpm}$$

0.145 gpm × 1440 min/d = 209 gpd

14,500 mg/L × 0.000209 MGD × 8.34 lb/gal = 25 lb/d

110. 535 lb/7 d = 76.4 lb/d average

111. $$\frac{2200 \text{ lb}}{90 \text{ lb/d}} = 24.4 \text{ d}$$

112. $$\frac{889 \text{ lb}}{58 \text{ lb/d}} = 15.3 \text{ d}$$

113. 0.785 × 3 ft × 3 ft × 3.4 ft × 7.48 gal/ft$^3$ = 180 gal

180 d/88 gpd = 2 d

114. 2.8 mg/L × 1.8 MGD × 8.34 lb/gal = 42 lb/d

42 lb/d × 30 d = 1260 lb

115. $$\frac{6{,}100{,}000 \text{ gpd}}{1440 \text{ min/d} \times 60 \text{ sec/min}} = 71 \text{ gps}$$

$$\frac{3 \text{ ft} \times 4 \text{ ft} \times 4 \text{ ft} \times 7.48 \text{ gal/ft}^3}{71 \text{ gps}} = 5 \text{ sec}$$

116. Volume (gal) = 50 ft × 20 ft × 9 ft × 7.48 gal/ft$^3$ = 67,320 gal

117. 9 mg/L × 4.35 MGD × 8.34 lb/gal = 326 lb/d

118. 10 mg/L × 3.15 MGD × 8.34 lb/gal = 500,000 mg/L × $x$ MGD × 8.34 lb/gal

$$\frac{10 \times 3.15 \times 8.34}{500{,}000 \times 8.34} = x$$

0.000063 MGD = $x$ = 63.0 gpd

119. 4 ft × 4 ft × 2 ft × 7.48 gal/ft$^3$ = 239 gal

120. $$\frac{45 \text{ gpd} \times 3785 \text{ mL/gal}}{1440 \text{ min/d}} = 118 \text{ mL/min}$$

121. $$\frac{2{,}220{,}000 \text{ gpd}}{1440 \text{ min/d}} = 1542 \text{ gpm}$$

$$\frac{40 \text{ ft} \times 20 \text{ ft} \times 9.17 \text{ ft} \times 7.48 \text{ gal/ft}^3}{1542 \text{ gpm}} = 36 \text{ min}$$

122. 8 mg/L × 1.84 MGD × 8.34 lb/gal = 600,000 mg/L × $x$ MGD × 10.2 lb/gal

$$\frac{8 \times 1.84 \times 8.34}{600,000 \times 10.2} = x \text{ MGD}$$

$x$ = 0.00002 MGD = 20.0 gpd

$$\frac{20.0 \text{ gpd} \times 3785 \text{ mL/gal}}{1440 \text{ min/d}} = 52.6 \text{ mL/min}$$

123. $$\frac{180 \text{ gpd} \times 3785 \text{ mL/gal}}{1440 \text{ min/d}} = 210 \text{ mL/min}$$

124. 6 mg/L × 0.925 MGD × 8.34 lb/gal = 46.3 lb/d

125. $$\frac{2.7 \text{ lb}}{x \text{ gal} \times 8.34 \text{ lb/gal} + 2.7 \text{ lb}} \times 100 = 1.4$$

$$\frac{270}{8.34\ x + 2.7} = 1.4$$

178.6 = 8.34$x$ + 2.7

175.9 = 8.34$x$

$$\frac{175.9}{8.34} = x$$

$x$ = 21.1 gal

126. $$\frac{\left[(16/100) \times 25 \text{ lb}\right] + \left[(0.6/100) \times 140 \text{ lb}\right]}{25 \text{ lb} + 140 \text{ lb}} \times 100$$

$$\frac{4 \text{ lb} + 0.84}{165 \text{ lb}} \times 100$$

$$\frac{4.84 \text{ lb}}{165 \text{ lb}} \times 100 = 2.9\%$$

127. $$\frac{4.0 \text{ lb chemical} \times 2}{30 \text{ min} \times 2} = \frac{8 \text{ lb}}{60 \text{ min}} \text{ or } 8 \text{ lb/hr}$$

8 lb/hr × 24 hr/d = 192 lb/d

128. 4.2 lb container and chemical – 2.0 lb container = 2.2 lb chemical

$$\frac{2.2 \text{ lb} \times 2}{30 \text{ min} \times 2} = \frac{4.4 \text{ lb}}{60 \text{ min}} = 4.4 \text{ lb/hr}$$

4.4 lb/hr × 24 lb/d = 105.6 lb/d

129. 190 g = 0.0022 lb × 190 = 0.42 lb

$$\frac{0.42 \text{ lb}}{25 \text{ gal} \times 8.34 \text{ lb/gal} + 0.42 \text{ lb}} \times 100 =$$

$$\frac{0.42}{208.5 + 0.42} \times 100 =$$

$$\frac{0.42}{208.9} \times 100 = 0.2\%$$

130. $\dfrac{760\text{ mL}}{5\text{ min}} = 152\text{ mL/min}$

$$\frac{152\text{ mL/min} \times 1440\text{ min/d}}{3785\text{ mL/gal}} = 58\text{ gpd}$$

20,000 mg/L $\times$ 0.000058 MGD $\times$ 8.34 lb/gal = 9.7 lb/d

131. 14 mg/L $\times$ 4.2 MGD $\times$ 8.34 lb/gal = 490 lb/d

$$\frac{490\text{ lb/d}}{4.66\text{ lb alum/gal solution}} = 86.6\text{ gpd}$$

132. (0.8/10) $\times$ 210 lb = 17 lb of 10% solution

(9.2/10) $\times$ 210 lb = 193 lb of water

133. 60% solution: (1/60) $\times$ 175 lb = 2.9 lb of 60% solution

Water: (59/60) $\times$ 75 lb = 172 lb of water

134. 3 in. ÷ 12 in./ft = 0.25 ft

$$\frac{0.785 \times 4\text{ ft} \times 4\text{ ft} \times 0.25\text{ ft} \times 7.47\text{ gal/ft}^3}{10\text{ min}} = 23\text{ gal/10 min} = 2.3\text{ gpm}$$

135. (10/100) $\times$ $x$ gal $\times$ 10.2 lb/gal = (0.6/100) $\times$ 80 gal $\times$ 8.34 lb/gal

$$x = \frac{0.006 \times 80 \times 8.34}{0.1 \times 10.2} = 3.9\text{ gal}$$

136. 710 mL/5 min = 142 mL/min

$$\frac{142\text{ mg/L/min} \times 1440\text{ min/d}}{3785\text{ mL/gal}} = 54\text{ gpd}$$

9000 mg/L $\times$ 0.0000540 MGD $\times$ 8.34 lb/gal = 4.1 lb/d

137. 6 mg/L $\times$ 3.7 MGD $\times$ 8.34 lb/gal = 185 lb/d

185 lb/d $\times$ 30 d = 5550 lb

138. $\dfrac{550\text{ lb}}{80\text{ lb/d}} = 6.9\text{ d}$

139. 70 ft $\times$ 30 ft $\times$ 14 ft $\times$ 7.48 gal/ft$^3$ = 219,912 gal

140. 0.785 $\times$ 80 ft $\times$ 80 ft $\times$ 12 ft $\times$ 7.48 gal/ft$^3$ = 450,954 gal

141. 70 ft $\times$ 20 ft $\times$ 10 ft $\times$ 7.48 gal/ft$^3$ = 104,720 gal

142. 50,000 gal = 40 ft $\times$ 25 ft $\times$ $x$ ft $\times$ 7.48 gal/ft$^3$

$$\frac{50{,}000}{40 \times 25 \times 7.48} = x$$

$x$ = 6.7 ft

143. 5 in. ÷ 12 in./ft = 0.42 ft

0.785 $\times$ 75 ft $\times$ 75 ft $\times$ 10.42 ft $\times$ 7.48 gal/ft$^3$ = 344,161 gal

144. $\dfrac{2{,}220{,}000}{24\text{ hr/d}} = 92{,}500\text{ gph}$

$$\frac{70\text{ ft} \times 25\text{ ft} \times 10\text{ ft} \times 7.48\text{ gal/ft}^3}{92{,}500\text{ gph}} = 1.4\text{ hr}$$

145. $$\frac{2{,}920{,}000\text{ gpd}}{24\text{ hr/d}} = 121{,}667\text{ gph}$$

$$\frac{0.785 \times 80\text{ ft} \times 80\text{ ft} \times 12\text{ ft} \times 7.48\text{ gal/ft}^3}{121{,}667\text{ gph}} = 3.7\text{ hr}$$

146. $$\frac{1{,}520{,}000\text{ gpd}}{24\text{ hr/d}} = 63{,}333\text{ gph}$$

$$\frac{60\text{ ft} \times 20\text{ ft} \times 10\text{ ft} \times 7.48\text{ gal/ft}^3}{63{,}333\text{ gph}} = 1.4\text{ hr}$$

147. $$3\text{ hr} = \frac{0.785 \times 60\text{ ft} \times 60\text{ ft} \times 12\text{ ft} \times 7.48\text{ gal/ft}^3}{x\text{ gph}}$$

$$x = \frac{0.785 \times 60 \times 60 \times 12 \times 7.48}{3}$$

$x$ = 84,554 gph

84,554 gph × 24 hr/d = 2,029,296 gpd = 2.0 MGD

148. $$\frac{1{,}740{,}000\text{ gpd}}{24\text{ hr/d}} = 72{,}500\text{ gph}$$

$$\frac{70\text{ ft} \times 25\text{ ft} \times 12\text{ ft} \times 7.48\text{ gal/ft}^3}{72{,}500\text{ gph}} = 2.2\text{ hr}$$

149. $$\frac{510\text{ gpm}}{60\text{ ft} \times 25\text{ ft}} = 0.34\text{ gpm/ft}^2$$

150. $$\frac{1610\text{ gpm}}{0.785 \times 70\text{ ft} \times 70\text{ ft}} = 0.42\text{ gpm/ft}^2$$

151. $$\frac{540{,}000\text{ gpd}}{1440\text{ min/d}} = 375\text{ gpm}$$

$$\frac{375\text{ gpm}}{50\text{ ft} \times 20\text{ ft}} = 0.38\text{ gpm/ft}^2$$

152. $$0.5\text{ gpm/ft}^2 = \frac{x\text{ gpm}}{80\text{ ft} \times 25\text{ ft}}$$

0.5 × 80 × 25 = $x$ gpm

1000 gpm = $x$

1000 gpm × 1440 min/d = 1,440,000 gpd

153. $$\frac{1{,}820{,}000\text{ gpd}}{1440\text{ min/d}} = 1264\text{ gpm}$$

$$\frac{1264\text{ gpm}}{0.785 \times 60\text{ ft} \times 60\text{ ft}} = 0.45\text{ gpm/ft}^2$$

154. $$\frac{1{,}550{,}000\text{ gpd}}{1440\text{ min/d} \times 7.48\text{ gal/ft}^3} = 144\text{ cfm}$$

144 cfm = 25 ft × 12 ft × $x$ fpm

$$\frac{144}{25 \times 12} = x$$

$x = 0.5$ fpm

155. $$\frac{1{,}800{,}000 \text{ gpd}}{1440 \text{ min/d} \times 7.48 \text{ gal/ft}^3} = 167 \text{ cfm}$$

167 cfm = 30 ft × 12 ft × $x$ fpm

$$\frac{167}{30 \times 12} = x$$

$x = 0.5$ fpm

156. $$\frac{2{,}450{,}000 \text{ gpd}}{1440 \text{ min/d} \times 7.48 \text{ gal/ft}^3} = 227 \text{ cfm}$$

227 cfm = 30 ft × 14 ft × $x$ fpm

$$\frac{227}{30 \times 14} = x$$

$x = 0.5$ fpm

157. $$\frac{2{,}880{,}000 \text{ gpd}}{1440 \text{ min/d} \times 7.48 \text{ gal/ft}^3} = 267 \text{ cfm}$$

267 cfm = 40 ft × 10 ft × $x$ fpm

$$\frac{267}{40 \times 12} = x$$

$x = 0.56$ fpm

158. $$\frac{910{,}000 \text{ gpd}}{1440 \text{ min/d} \times 7.48 \text{ gal/ft}^3} = 84.5 \text{ cfm}$$

84.5 cfm = 25 ft × 10 ft × $x$ fpm

$$\frac{84.5}{25 \times 10} = x$$

$x = 0.4$ fpm

159. $$\frac{2{,}520{,}000 \text{ gpd}}{1440 \text{ min/d}} = 1750 \text{ gpm}$$

$$\frac{1750 \text{ gpm}}{3.14 \times 70 \text{ ft}} = 7.9 \text{ gpm/ft}$$

160. $$\frac{1{,}890{,}000 \text{ gpd}}{1440 \text{ min/d}} = 1313 \text{ gpm}$$

$$\frac{1313 \text{ gpm}}{170 \text{ ft}} = 7.7 \text{ gpm/ft}$$

161. $$\frac{1{,}334{,}000 \text{ gpd}}{1440 \text{ min/d}} = 926 \text{ gpm}$$

$$\frac{926 \text{ gpm}}{120 \text{ ft}} = 7.7 \text{ gpm/ft}$$

162. $$\frac{3,700,000 \text{ gpd}}{1440 \text{ min/d}} = 2569 \text{ gpm}$$

$$\frac{2569 \text{ gpm}}{3.14 \times 70 \text{ ft}} = 11.7 \text{ gpm/ft}$$

163. $$\frac{1,900,000 \text{ gpd}}{1440 \text{ min/d}} = 1319 \text{ gpm}$$

$$\frac{1319 \text{ gpm}}{160 \text{ ft}} = 8.2 \text{ gpm/ft}$$

164. $$\frac{22 \text{ mL}}{100 \text{ mL}} \times 100 = 22\%$$

165. $$\frac{25 \text{ mL}}{100 \text{ mL}} \times 100 = 25\%$$

166. $$\frac{15 \text{ mL}}{100 \text{ mL}} \times 100 = 15\%$$

167. $$\frac{16 \text{ mL}}{100 \text{ mL}} \times 100 = 16\%$$

168. $$\frac{0.45 \text{ mg/L alkalinity}}{1 \text{ mg/L alum}} = \frac{x \text{ mg/L alkalinity}}{52 \text{ mg/L alum}}$$

$0.45 \times 52 = x = 23.4$ mg/L

23.4 mg/L + 40 mg/L = 63.4 mg/L

169. $$\frac{0.45 \text{ mg/L alkalinity}}{1 \text{ mg/L alum}} = \frac{x \text{ mg/L alkalinity}}{60 \text{ mg/L alum}}$$

$0.45 \times 60 = x = 27$ mg/L

27 mg/L + 30 mg/L = 57 mg/L

170. 40 mg/L – 26 mg/L = 14 mg/L alkalinity to be added

171. 40 mg/L – 28 mg/L = 12 mg/L alkalinity to be added

172. $$\frac{0.45 \text{ mg/L alkalinity}}{0.45 \text{ mg/L lime}} = \frac{15 \text{ mg/L alkalinity}}{x \text{ mg/L lime}}$$

$0.45x = 15 \times 0.45$

$$x = \frac{15 \times 0.45}{0.45}$$

$x = 15$ mg/L lime

173. $$\frac{0.45 \text{ mg/L alkalinity}}{0.35 \text{ mg/L lime}} = \frac{20 \text{ mg/L alkalinity}}{x \text{ mg/L lime}}$$

$0.45x = 20 \times 0.35 = x$

$$x = \frac{20 \times 0.35}{0.45}$$

$x = 15.6$ mg/L lime

174. $\dfrac{0.45 \text{ mg/L alkalinity}}{1 \text{ mg/L alum}} = \dfrac{x \text{ mg/L alkalinity}}{55 \text{ mg/L alum}}$

$0.45 \times 55 = x = 24.8$ mg/L alkalinity

24.8 mg/L + 30 mg/L = 54.8 mg/L total alkalinity required

54.8 mg/L – 35 mg/L = 19.8 mg/L alkalinity to be added to the water

$\dfrac{0.45 \text{ mg/L alkalinity}}{0.35 \text{ mg/L}} = \dfrac{19.8 \text{ mg/L alkalinity}}{x \text{ mg/L lime}}$

$0.45x = 19.8 \times 0.35$

$x = \dfrac{19.8 \times 0.35}{0.45}$

$x = 15.4$ mg/L lime

175. 13.8 mg/L × 2.7 MGD × 8.34 lb/gal = 311 lb/d lime

176. 12.3 mg/L × 2.24 MGD × 8.34 lb/gal = 230 lb/d lime

177. 16.1 mg/L × 0.99 MGD × 8.34 lb/gal = 133 lb/d lime

178. 15 mg/L × 2.2 MGD × 8.34 lb/gal = 275 lb/d lime

179. $\dfrac{205 \text{ lb/d} \times 453.6 \text{ g/lb}}{1440 \text{ min/d}} = 64.6 \text{ g/min lime}$

180. $\dfrac{110 \text{ lb/d} \times 453.6 \text{ g/lb}}{1440 \text{ min/d}} = 34.7 \text{ g/min lime}$

181. 12 mg/L × 0.90 MGD × 8.34 lb/gal = 90 lb/d lime

$\dfrac{90 \text{ lb/d} \times 453.6 \text{ g/lb}}{1440 \text{ min/d}} = 28.4 \text{ g/min lime}$

182. 14 mg/L × 2.66 MGD × 8.34 lb/gal = 310.1 lb/d lime

$\dfrac{310.1 \text{ lb/d} \times 453.6 \text{ g/lb}}{1440 \text{ min/d}} = 97.7 \text{ g/min lime}$

183. $\dfrac{1,550,000 \text{ gpd}}{24 \text{ hr/d}} = 64,583 \text{ gph}$

$\dfrac{66 \text{ ft} \times 30 \text{ ft} \times 12 \text{ ft} \times 7.48 \text{ gal/ft}^3}{64,583} = 2.8 \text{ hr}$

184. 70 ft × 30 ft × 7.48 gal/ft$^3$ = 219,912 gal

185. $\dfrac{1,620,000 \text{ gpd}}{1440 \text{ min/d} \times 7.48 \text{ gal/ft}^3} = 150 \text{ cfm}$

150 cfm = 25 ft × 12 ft × $x$ fpm

$\dfrac{150}{25 \times 12} = x$

$x = 0.5$ fpm

186. $\dfrac{635,000 \text{ gpd}}{1440 \text{ min/d}} = 441 \text{ gpm}$

$\dfrac{441 \text{ gpm}}{40 \text{ ft} \times 25 \text{ ft}} = 0.44 \text{ gpm/ft}^2$

187. $0.785 \times 70 \text{ ft} \times 70 \text{ ft} \times 14 \text{ ft} \times 7.48 \text{ gal/ft}^3 = 402{,}805 \text{ gal}$

188. $$\frac{2{,}220{,}000 \text{ gpd}}{1440 \text{ min/d}} = 1542 \text{ gpm}$$

$$\frac{1542 \text{ gpm}}{180 \text{ ft}} = 8.6 \text{ gpm/ft}$$

189. $$\frac{2{,}560{,}000 \text{ gpd}}{24 \text{ hr/d}} = 106{,}667 \text{ gph}$$

$$\frac{0.785 \times 60 \text{ ft} \times 60 \text{ ft} \times 10 \text{ ft} \times 7.48 \text{ gal/ft}^3}{106{,}667 \text{ gph}} = 1.98 \text{ hr}$$

190. $$\frac{1{,}750{,}000 \text{ gpd}}{1440 \text{ min/d} \times 7.48 \text{ gal/ft}^3} = 162 \text{ cfm}$$

$162 \text{ cfm} = 30 \text{ ft} \times 12 \text{ ft} \times x \text{ fpm}$

$$\frac{162}{30 \times 12} = x$$

$x = 0.45$

191. $$\frac{1700 \text{ gpm}}{0.785 \times 70 \text{ ft} \times 70 \text{ ft}} = 0.4 \text{ gpm/ft}^2$$

192. $$\frac{3{,}150{,}000 \text{ gpd}}{1440 \text{ min/d}} = 2188 \text{ gpm}$$

$$\frac{2188 \text{ gpm}}{3.14 \times 70 \text{ ft}} = 9.9 \text{ gpm}$$

193. $$2 \text{ hr} = \frac{0.785 \times 60 \text{ ft} \times 60 \text{ ft} \times 12 \text{ ft} \times 7.48 \text{ gal/ft}^3}{x \text{ gph}}$$

$$x = \frac{0.785 \times 60 \times 60 \times 12 \times 7.48}{2}$$

$x = 126{,}831$

$126{,}831 \text{ gph} \times 24 \text{ hr/d} = 3{,}043{,}944 \text{ gpd}$ (3.04 MGD)

194. $$\frac{3{,}250{,}000 \text{ gpd}}{1440 \text{ min/d} \times 7.48 \text{ gal/ft}^3} = 302 \text{ cfm}$$

$302 \text{ cfm} = 30 \text{ ft} \times 14 \text{ ft} \times x \text{ fpm}$

$$\frac{302}{30 \times 14} = x$$

$x = 0.7 \text{ fpm}$

195. $$\frac{26 \text{ mL}}{100 \text{ mL}} \times 100 = 26\%$$

196. $$\frac{1 \text{ mg/L alum}}{0.45 \text{ mg/L alkalinity}} = \frac{50 \text{ mg/L alum}}{x \text{ mg/L alkalinity}}$$

$0.45 \times 50 = x = 22.5 \text{ mg/L}$

Total alkalinity required (mg/L) = 22.5 mg/L + 30 mg/L = 52.5 mg/L

197. $0.7\ \text{gpm/ft}^2 = \dfrac{x\ \text{gpm}}{80\ \text{ft} \times 30\ \text{ft}}$

$0.7 \times 80 \times 30 = x = 1680$

$1680\ \text{gpm} \times 1440\ \text{min/d} = 2{,}419{,}200\ \text{gpd}$

198. $14.5\ \text{mg/L} \times 2.41\ \text{MGD} \times 8.34\ \text{lb/gal} = 291\ \text{lb/d}$

199. $\dfrac{21\ \text{mL}}{100\ \text{mL}} \times 100 = 21\%$ settled sludge

200. $\dfrac{3{,}240{,}000\ \text{gpd}}{1440\ \text{min/d}} = 2250\ \text{gpm}$

$$\frac{2250\ \text{gpm}}{3.14 \times 80\ \text{ft}} = 9.0\ \text{gpm/ft}$$

201. $50\ \text{mg/L} - 30\ \text{mg/L} = 10\ \text{mg/L}$ alkalinity to be added to the water

202. $\dfrac{0.45\ \text{mg/L alkalinity}}{1\ \text{mg/L alum}} = \dfrac{x\ \text{mg/L alkalinity}}{50\ \text{mg/L alum}}$

$0.45 \times 50 = x = 22.5$ mg/L alkalinity

$22.5\ \text{mg/L} + 30\ \text{mg/L} = 52.5$ mg/L alkalinity required

$52.5\ \text{mg/L} - 33\ \text{mg/L} = 19.5$ mg/L alkalinity to be added

$$\frac{0.45\ \text{mg/L alkalinity}}{0.35\ \text{mg/L lime}} = \frac{19.5\ \text{mg/L alkalinity}}{x\ \text{mg/L lime}}$$

$$x = \frac{19.5 \times 0.35}{0.45}$$

$x = 15.2$ mg/L lime

203. $\dfrac{192\ \text{lb/d lime} \times 453.6\ \text{g/lb}}{1440\ \text{min/d}} = 60.5\ \text{g/min}$

204. $16\ \text{mg/L} \times 1.5\ \text{MGD} \times 8.34\ \text{lb/gal} = 200\ \text{lb/d}$

205. $\dfrac{\text{Lime (lb/d)} \times 453.6\ \text{g/lb}}{1440\ \text{min/d}} = \text{lime (g/min)}$

$$\frac{14\ \text{mg/L} \times 2.88\ \text{MGD} \times 8.34\ \text{lb/gal} \times 453.6\ \text{g/lb}}{1440\ \text{min/d}} = 106\ \text{g/min lime}$$

206. $\dfrac{14{,}200{,}000\ \text{gal}}{80\ \text{hr} \times 60\ \text{min/lb}} = 2958\ \text{gpm}$

207. $\dfrac{2{,}970{,}000\ \text{gpd}}{1440\ \text{min/d}} = 2063\ \text{gpm}$

208. $3200\ \text{gpm} = \dfrac{16{,}000{,}000\ \text{gal}}{x\ \text{hr} \times 60\ \text{min/hr}}$

$$x = \frac{16{,}000{,}000}{3200 \times 60}$$

$x = 83$ hr

209. $45\ \text{ft} \times 22\ \text{ft} \times 1\text{ft}/5\ \text{min} \times 7.48\ \text{gal/ft}^3 = 1481\ \text{gpm}$

210. 14 in./12 in. = 1.17 ft

$40 \text{ ft} \times 30 \text{ ft} \times (1.17 \text{ ft}/5 \text{ min}) \times 7.48 \text{ gal/ft}^3 = 2100 \text{ gpm}$

211. 18 in./12 in. = 1.5 ft

$35 \text{ ft} \times 18 \text{ ft} \times (1.5 \text{ ft}/6 \text{ min}) \times 7.48 \text{ gal/ft}^3 = 1178 \text{ gpm}$

212. $$\frac{1760 \text{ gpm}}{20 \text{ ft} \times 18 \text{ ft}} = 4.9 \text{ gpm/ft}^2$$

213. $$\frac{2{,}150{,}000 \text{ gal}}{1440 \text{ min/d}} = 1493 \text{ gpm}$$

$$\frac{1493 \text{ gpm}}{32 \text{ ft} \times 18 \text{ ft}} = 2.6 \text{ gpm/ft}^2$$

214. $$\frac{18{,}000{,}000 \text{ gal}}{71.6 \text{ hr} \times 60 \text{ min/hr}} = 4213 \text{ gpm}$$

$$\frac{4213 \text{ gpm}}{38 \text{ ft} \times 24 \text{ ft}} = 4.6 \text{ gpm/ft}^2$$

215. $$\frac{14{,}200{,}000 \text{ gal}}{71.4 \text{ hr} \times 60 \text{ min/hr}} = 3315 \text{ gpm}$$

$$\frac{3315 \text{ gpm}}{33 \text{ ft} \times 24 \text{ ft}} = 4.2 \text{ gpm/ft}^2$$

216. $$\frac{3{,}550{,}000 \text{ gpd}}{1440 \text{ min/d}} = 2465 \text{ gpm}$$

$$\frac{2465 \text{ gpm}}{88 \text{ ft} \times 22 \text{ ft}} = 2.9 \text{ gpm/ft}^2$$

217. 22 in. ÷ 12 in/ft = 1.83 ft

$38 \text{ ft} \times 18 \text{ ft} \times 1.83/5 \text{ min} \times 7.48 \text{ gal/ft}^3 = 1873 \text{ gpm}$

$$\frac{1873 \text{ gpm}}{38 \text{ ft} \times 18 \text{ ft}} = 2.7 \text{ gpm/ft}^2$$

218. 21 in. ÷ 12 in./ft = 1.8 ft

$33 \text{ ft} \times 24 \text{ ft} \times (1.8 \text{ ft}/6 \text{ min}) \times 7.48 \text{ gal/ft}^3 = 1777 \text{ gpm}$

$$\frac{1777 \text{ gpm}}{33 \text{ ft} \times 24 \text{ ft}} = 2.2 \text{ gpm/ft}^2$$

219. $$\frac{2{,}870{,}000 \text{ gal}}{20 \text{ ft} \times 18 \text{ ft}} = 7972 \text{ gal/ft}^2$$

220. $$\frac{4{,}180{,}000 \text{ gal}}{32 \text{ ft} \times 20 \text{ ft}} = 6533 \text{ gal/ft}^2$$

221. $$\frac{2{,}980{,}000 \text{ gal}}{24 \text{ hr} \times 18 \text{ ft}} = 6898 \text{ gal/ft}^2$$

222. $3.4 \text{ gpm/ft}^2 \times 3330 \text{ min} = 11{,}322 \text{ gal/ft}^2$

223. $2.6 \text{ gpm/ft}^2 \times 60.5 \text{ hr} \times 60 \text{ min/hr} = 9438 \text{ gal/ft}^2$

224. $\dfrac{3510 \text{ gpm}}{380 \text{ ft}^2} = 9.2 \text{ gpm/ft}^2$

225. $\dfrac{3580 \text{ gpm}}{18 \text{ ft} \times 14 \text{ ft}} = 14.2 \text{ gpm/ft}^2$

226. $\dfrac{16 \text{ gpm/ft}^2 \times 12 \text{ in./ft}}{7.48 \text{ gal/ft}^2} = 25.7 \text{ in./min}$

227. $\dfrac{3650 \text{ gpm}}{30 \text{ ft} \times 18 \text{ ft}} = 6.8 \text{ gpm/ft}^2$

228. $\dfrac{3080 \text{ gpm}}{18 \text{ ft} \times 14 \text{ ft}} = 12.2 \text{ gpm/ft}^2$

$12.2 \text{ gpm/ft}^2 \times 1.6 = 19.5$ in./min rise

229. 6650 gpm × 6 min = 39,900 gal

230. 9100 gpm × 7 min = 63,700 gal

231. 4670 gpm × 5 min = 23,350 gal

232. 6,750 gpm × 6 min = 40,500 gal

233. $59{,}200 \text{ gal} = 0.785 \times 40 \text{ ft} \times 40 \text{ ft} \times x \text{ ft} \times 7.48 \text{ gal/ft}^3$

$$\frac{59{,}200}{0.785 \times 40 \times 40 \times 7.48} = x$$

$x = 6.3$ ft

234. $62{,}200 \text{ gal} = 0.785 \times 52 \text{ ft} \times 52 \text{ ft} \times x \text{ ft} \times 7.48 \text{ gal/ft}^3$

$$\frac{62{,}200}{0.785 \times 52 \times 52 \times 7.48} = x$$

$x = 3.9$ ft

235. $42{,}300 \text{ gal} = 0.785 \times 42 \text{ ft} \times 42 \text{ ft} \times x \text{ ft} \times 7.48 \text{ gal/ft}^3$

$$\frac{42{,}300 \text{ gal}}{0.785 \times 42 \times 42 \times 7.48} = x$$

$x = 4.1$ ft

236. 7150 gpm × 7 min = 50,050 gal

$50{,}050 \text{ gal} = 0.785 \times 40 \text{ ft} \times 40 \text{ ft} \times x \text{ ft} \times 7.48 \text{ gal/ft}^3$

$$\frac{50{,}050}{0.785 \times 40 \times 40 \times 7.48} = x$$

$x = 5.3$ ft

237. 8860 gpm × 6 min = 53,160 gal

$53{,}160 \text{ gal} = 0.785 \times 40 \text{ ft} \times 40 \text{ ft} \times x \text{ ft} \times 7.48 \text{ gal/ft}^3$

$$\text{Backwash pumping rate (gpm)} = \frac{53{,}160}{0.785 \times 40 \times 40 \times 7.48 \text{ gal/ft}^3} = x$$

$x = 5.7$ ft

238. $19 \text{ gpm/ft}^2 \times 42 \text{ ft} \times 22 \text{ ft} = 17{,}556$ gpm

239. $20 \text{ gpm/ft}^2 \times 36 \text{ ft} \times 26 \text{ ft} = 18{,}720$ gpm

240. $16 \text{ gpm/ft}^2 \times 22 \text{ ft} \times 22 \text{ ft} = 7744$ gpm

241. 24 gpm/ft$^2$ × 26 ft × 22 ft = 13,728 gpm

242. $\dfrac{74{,}200 \text{ gal}}{17{,}100{,}000 \text{ gal}} \times 100 = 0.43\%$

243. $\dfrac{37{,}200 \text{ gal}}{6{,}100{,}000 \text{ gal}} \times 100 = 0.61\%$ backwash water

244. $\dfrac{59{,}400 \text{ gal}}{13{,}100{,}000 \text{ gal}} \times 100 = 0.45\%$ backwash water

245. $\dfrac{52{,}350 \text{ gal}}{11{,}110{,}000 \text{ gal}} \times 100 = 0.47\%$

246. Mud ball volume = 635 mL – 600 mL = 35 mL

$$\frac{35 \text{ mL}}{3625 \text{ mL}} \times 100 = 0.97\%$$

247. Mud ball volume = 535 mL – 510 mL = 25 mL
Total sample volume = 5 × 705 mL = 3525 mL

$$\frac{25 \text{ mL}}{3525 \text{ mL}} \times 100 = 0.7\%$$

248. Mud ball volume = 595 mL – 520 mL = 75 mL
Total sample volume = 5 × 705 mL = 3525 mL

$$\frac{75 \text{ mL}}{3525 \text{ mL}} \times 100 = 2.2\%$$

249. Mud ball volume = 562 mL – 520 mL = 42 mL
Total sample volume = 5 × 705 mL = 3525 mL

$$\frac{42 \text{ mL}}{3525 \text{ mL}} \times 100 = 1.2\%$$

250. $\dfrac{11{,}400{,}000 \text{ gal}}{80 \text{ hr} \times 60 \text{ min/hr}} = 2375 \text{ gpm}$

251. $\dfrac{3{,}560{,}000 \text{ gpd}}{1440 \text{ min/d}} = 2472 \text{ gpm}$

$$\frac{2472 \text{ gpm}}{40 \text{ ft} \times 25 \text{ ft}} = 2.5 \text{ gpm}$$

252. $\dfrac{2{,}880{,}000 \text{ gal}}{25 \text{ ft} \times 25 \text{ ft}} = 4608 \text{ gal/ft}^2$

253. $2900 \text{ gpm} = \dfrac{14{,}800{,}000 \text{ gal}}{x \text{ hr} \times 60 \text{ min/hr}}$

$$x = \frac{14{,}800{,}000}{2900 \times 60}$$

$x$ = 85.1 hr

254. 14 in./12 in. = 1.17 ft
38 ft × 26 ft × 1.17 ft/5 min = 231 cfm
231 cfm × 7.48 gal/ft$^3$ = 1728 gpm

255. $\frac{3{,}450{,}000 \text{ gal}}{30 \text{ ft} \times 25 \text{ ft}} = 4600 \text{ gal/ft}^2$

256. $\frac{13{,}500{,}000 \text{ gal}}{73.8 \text{ hr} \times 60 \text{ min/hr}} = 3049 \text{ gpm}$

$$\frac{3049 \text{ gpm}}{30 \text{ ft} \times 20 \text{ ft}} = 5.1 \text{ gpm/ft}^2$$

257. $\frac{3220 \text{ gpm}}{360 \text{ ft}^2} = 8.9 \text{ gpm/ft}^2$

258. 6,350 gpm × 6 min = 38,100 gal

259. 14 in./12 in. = 1.2 ft

30 ft × 22 ft × 1.2 ft/5 min × 7.48 gal/ft$^3$ = 1185 gpm

$$\text{Flow rate } \left(\text{gpm/ft}^2\right) = \frac{1185 \text{ gpm}}{30 \text{ ft} \times 22 \text{ ft}} = 1.8 \text{ gpm/ft}^2$$

260. 53,200 gal = 0.785 × 45 ft × 45 ft × $x$ ft × 7.48 gal/ft$^3$

$$\frac{53{,}200}{0.785 \times 45 \times 45 \times 7.48} = x$$

$x$ = 4.5 ft

261. 3.3 gpm/ft$^2$ × 3620 min = 11,946 gal/ft$^2$

262. 20 in./12 in. = 1.7 ft

40 ft × 25 ft × 1.7 ft/5 min × 7.48 gal/ft$^3$ = 2543 gpm

$$\text{Flow rate } \left(\text{gpm/ft}^2\right) = \frac{2543 \text{ gpm}}{40 \text{ ft} \times 25 \text{ ft}} = 2.5 \text{ gpm/ft}^2$$

263. $\frac{3800 \text{ gpm}}{35 \text{ ft} \times 25 \text{ ft}} = 4.3 \text{ gpm/ft}^2$

264. 4500 gpm × 7 min = 31,500 gal

265. 16 gpm/ft$^2$ × 30 ft × 30 ft = 14,400 gpm

266. $\frac{2800 \text{ gpm}}{25 \text{ ft} \times 20 \text{ ft}} = 5.6 \text{ gpm/ft}^2$

$$\frac{5.6 \text{ gpm/ft}^2 \times 12 \text{ in./ft}}{7.48 \text{ gal/ft}^3} = 8.9 \text{ in./min}$$

267. 18 in./12 in. = 1.5 ft

30 ft × 25 ft × 1.5/6 min × 7.48 gal/ft$^3$ = 1403 gpm

$$\frac{1403}{30 \text{ ft} \times 25 \text{ ft}} = 1.9 \text{ gpm/ft}^2$$

268. 18 gpm/ft$^2$ × 45 ft × 25 ft = 20,250 gpm

269. $\frac{71{,}350 \text{ gal}}{18{,}200{,}000 \text{ gal}} \times 100 = 0.39 \text{ gal}$

270. 86,400 gal = 0.785 × 35 ft × 35 ft × $x$ ft × 7.48 gal/ft$^3$

$$\frac{86{,}400}{0.785 \times 35 \times 35 \times 7.48} = 12 \text{ ft}$$

271. 527 mL – 500 mL = 27 mL

$$\frac{27 \text{ mL}}{3480 \text{ mL}} \times 100 = 0.8\%$$

272. $$\frac{51,200 \text{ gal}}{13,800,000 \text{ gal}} \times 100 = 0.37\%$$

273. 571 – 500 mL = 71 mL

$$\frac{71 \text{ mL}}{5 \times 695 \text{ mL}} \times 100 = 2\%$$

274. (a) $$\frac{3,700,000 \text{ gal}}{36 \text{ hr}/500 \text{ ft}^2} \times \frac{1 \text{ hr}}{60 \text{ min}} = 3.4 \text{ gpm}/\text{ft}^2$$

(b) 12 gpm/$\text{ft}^2$ × 15 min × 500 $\text{ft}^2$ = 90,000 gal

(c) $$\frac{90,000 \text{ gal}}{3,700,000 \text{ gal}} \times 100 = 2.4\%$$

(d) 70 ft – 25 ft = 45 ft

(e) $$\frac{3,700,000}{500 \text{ ft}^2} = 7400 \text{ gal}/\text{ft}^2$$

275. 1.8 mg/L × 3.5 MGD × 8.34 lb/gal = 52.5 lb/d chlorine

276. 2.5 mg/L × 1.34 MGD × 8.34 lb/gal = 28 lb/d

277. 0.785 × 1 ft × 1 ft × 1200 ft × 7.48 gal/$\text{ft}^3$ = 7046 gal

52 mg/L × 0.007046 MG × 8.34 lb/gal = 3.1 lb chlorine

278. $x$ mg/L × 3.35 MGD × 8.34 lb/gal = 43 lb

$$x = \frac{43}{3.35 \times 8.34}$$

$x$ = 1.5 mg/L

279. 19,222,420 gal –18,815,108 gal = 407,312 gal

407,312 gal/24 hr = 0.407 MGD

$$x = \frac{16}{0.407 \times 8.34}$$

$x$ = 4.7 mg/L

280. 1.6 mg/L + 0.5 mg/L = 2.1 mg/L

281. 2.9 mg/L = $x$ mg/L + 0.7 mg/L

2.9 – 0.7 = $x$ mg/L

$x$ = 2.2 mg/L

282. 2.6 mg/L + 0.8 mg/L = 3.4 mg/L

3.4 mg/L × 3.85 MGD × 8.34 lb/gal = 110 lb/d

283. $x$ mg/L × 1.10 MGD × 8.34 lb/gal = 6 lb/d

$$x = \frac{6}{1.10 \times 8.34}$$

$x$ = 0.65 mg/L

0.8 mg/L – 0.65 mg/L = 0.15 mg/L

The expected increase in residual was 0.65 mg/L, whereas the actual increase in residual was only 0.15 mg/L. From this analysis, it appears the water is not being chlorinated beyond the breakpoint.

284. $x$ mg/L × 2.10 MGD × 8.34 lb/gal = 5 lb/d

$$x = \frac{5}{210 \times 8.34}$$

$x$ = 0.29 mg/L

0.5 mg/L – 0.4 mg/L = 0.1 mg/L

The expected chlorine residual increase (0.29 mg/L) is consistent with the actual increase in chlorine residual (0.1 mg/L); thus, it appears as though the water is not being chlorinated beyond the breakpoint.

285. $$\frac{48 \text{ lb/d}}{0.65} = 73.8 \text{ lb/d hypochlorite}$$

286. $$\frac{42 \text{ lb/d}}{0.65} = 64.6 \text{ lb/d hypochlorite}$$

287. 2.7 mg/L × 0.928 MGD × 8.34 lb/gal = 21 lb/d chlorine

$$\frac{21 \text{ lb/d}}{0.65} = 32.3 \text{ lb/d hypochlorite}$$

288. $$54 \text{ lb/d} = \frac{x \text{ lb/d}}{0.65}$$

$x$ = 54 × 0.65 = 35.1 lb/d chlorine

$x$ mg/L × 1.512 MGD × 8.34 lb/gal = 35.1 lb/d

$$x = \frac{35.1}{1.512 \text{ MGD} \times 8.34} = 2.8 \text{ mg/L}$$

289. $$49 \text{ lb/d} = \frac{x \text{ lb/d}}{0.65}$$

$x$ = 49 × 0.65 = 31.9 lb/d chlorine

$x$ mg/L × 3.210 MGD × 8.34 lb/gal = 31.9 lb/d

$$x = \frac{31.9}{3.210 \times 8.34}$$

$x$ = 1.2 mg/L

290. $$\frac{36 \text{ lb/d}}{8.34 \text{ lb/d}} = 4.3 \text{ gpd hypochlorite}$$

291. 2.9 mg/L × 0.785 MGD × 8.34 lb/gal = 120,000 mg/L × $x$ MGD × 8.34 lb/gal

$$x = \frac{2.9 \times 0.785 \times 8.34}{120{,}000 \times 8.34}$$

$x$ = 0.0000189 MGD = 18.9 gpd

292. 2.2 mg/L × 0.245 MGD × 8.34 lb/gal = 30,000 mg/L × $x$ MGD × 8.34 lb/gal

$$x = \frac{2.2 \times 0.245 \times 8.34}{30{,}000 \times 8.34}$$

0.0000179 MGD = $x$ = 17.9

293. $$\frac{2{,}330{,}000 \text{ gal}}{7 \text{ d}} = 332{,}857 \text{ gpd}$$

$$\frac{0.785 \times 3\text{ ft} \times 2.83\text{ ft} \times 7.48\text{ gal/ft}^3}{7\text{ d}} = 21.4\text{ gpd}$$

$x$ mg/L × 0.332 MGD × 8.34 lb/gal = 30,000 mg/L × 0.0000214 MGD × 8.34 lb/gal

$$x = \frac{30,000 \times 0.0000214 \times 8.34}{0.332 \times 8.34}$$

$x$ = 1.9 mg/L

294. 400 gpm × 1440 min/d = 576,000 gpd = 0.576 MGD

1.8 mg/L × 0.576 MGD × 8.34 lb/gal = 40,000 mg/L × $x$ MGD × 8.34 lb/gal

$$x = \frac{1.8 \times 0.576 \times 8.34}{40,000 \times 8.34}$$

$x$ = 0.0000259 MGD = 25.9 gpd

295. 2.9 mg/L × 0.955 MGD × 8.34 lb/gal = (30,000 mg/L × $x$ MGD × 8.34 lb/gal)

$$x = \frac{2.9 \times 0.955 \times 8.34}{30,000 \times 8.34}$$

$x$ = 0.0000923 MGD = 923 MGD

296. $$\frac{22\text{ lb} \times 0.65}{(60\text{ gal} \times 8.34\text{ lb/gal}) + (22\text{ lb} \times 0.65)} \times 100$$

$$\frac{14.3\text{ lb}}{500.4\text{ lb} + 14.3\text{ lb}} \times 100$$

$$\frac{14.3\text{ lb}}{514.7\text{ lb}} \times 100 = 2.8\%\text{ chlorine}$$

297. 320 g × 0.0022 lb/g = 0.70 lb hypochlorite

$$\frac{0.70\text{ lb} \times 0.65}{(7\text{ gal} \times 8.34\text{ lb/gal}) + (0.70\text{ lb} \times 0.65)} \times 100$$

$$\frac{0.46\text{ lb}}{58.4 + 0.46} \times 100$$

$$\frac{0.46\text{ lb}}{58.9\text{ lb}} \times 100 = 0.79\%\text{ chlorine}$$

298. $$3 = \frac{x\text{ lb} \times 0.65}{(65\text{ gal} \times 8.34\text{ lb/gal}) + (x\text{ lb} \times 0.65)} \times 100$$

$$3 = \frac{x \times 0.65 \times 100}{542.1 + 0.65\,x}$$

$$3 = \frac{65\,x}{542.1 + 0.65\,x} = 21.7\,x$$

$$542.8 = 21.7\,x$$

$$\frac{542.8}{21.7} = x$$

$$x = 25\text{ lb}$$

299. $x$ gal × 8.34 × (10/100) = 35 gal × 8.34 × (2/100)

$$x = \frac{35 \times 8.34 \times 0.02}{8.34 \times 0.10}$$

$x$ = 7 gal

300. $x$ gal × 8.34 × (13/100) = 110 gal × 8.34 × (1.2/100)

$$x = \frac{110 \times 8.34 \times 0.012}{8.34 \times 0.13}$$

$x$ = 10.2 gal

301. 6 gal × 8.34 × (12/100) = $x$ gal × 8.34 × (2/100)

$$x = \frac{6 \times 8.34 \times 0.12}{8.34 \times 0.02}$$

$x$ = 36 gal solution

Because the solution contains 6 gal liquid hypochlorite, a total of 36 gal – 6 gal = 30 gal water must be added.

302. $$\frac{(50 \text{ lb} \times 0.11) + (220 \text{ lb} \times 0.01)}{50 \text{ lb} + 220 \text{ lb}} \times 100$$

$$\frac{5.5 \text{ lb} + 2.2 \text{ lb}}{270 \text{ lb}} \times 100$$

$$\frac{7.7 \text{ lb}}{270 \text{ lb}} \times 100 = 2.85\%$$

303. $$\frac{[12 \text{ gal} \times 8.34 \text{ lb/gal} \times (12/100)] + [60 \text{ gal} \times 8.34 \text{ lb/gal} \times (1.5/100)]}{(12 \text{ gal} \times 8.34 \text{ lb/gal}) + (60 \text{ gal} \times 8.34 \text{ lb/gal})} \times 100$$

$$\frac{12 \text{ gal} + 7.5 \text{ lb}}{100 \text{ lb} + 500 \text{ lb}} \times 100$$

$$\frac{19.5 \text{ lb}}{600 \text{ lb}} \times 100 = 3.3\%$$

304. $$\frac{[16 \text{ gal} \times 8.34 \text{ lb/gal} \times (12/100)] + [70 \text{ gal} \times 8.34 \text{ lb/gal} \times (1/100)]}{(16 \text{ gal} \times 8.34 \text{ lb/gal}) + (70 \text{ gal} \times 8.34 \text{ lb/gal})} \times 100$$

$$\frac{16 \text{ gal} + 5.8 \text{ lb}}{133.4 \text{ lb} + 583.8 \text{ lb}} \times 100$$

$$\frac{21.8 \text{ lb}}{717.2 \text{ lb}} \times 100 = 3.0\%$$

305. $$\frac{1000 \text{ lb}}{44 \text{ lb/d}} = 22.7 \text{ d}$$

306. 8 in./12 in. = 0.67 ft

$$x \text{ d} = \frac{0.785 \times 4 \text{ ft} \times 4 \text{ ft} \times 3.67 \text{ ft} \times 7.48 \text{ gal/ft}^3}{80 \text{ gpd}}$$

= 345/80 = 4.3 d supply

307. $\frac{24\text{ lb/d} \times 150\text{ hr operation}}{24\text{ lb/d}} = 150\text{ lb chlorine}$

308. $\frac{12\text{ lb/d}}{24\text{ hr/d}} \times 111\text{ hr operation} = 55.5\text{ lb}$

91 lb – 55.5 lb = 35.5 lb remaining

309. 55 lb/d × 30 d = 1650 lb chlorine/month

$\frac{1650\text{ lb chlorine}}{150\text{ lb/cylinder}} = 11\text{ chlorine cylinders}$

310. $2\text{ d} = \frac{0.785 \times 3\text{ ft} \times 3\text{ ft} \times x\text{ ft} \times 7.48\text{ gal/ft}^3}{52\text{ gpd}}$

$x = \frac{20 \times 52}{0.785 \times 3 \times 3 \times 7.48}$

$x = \frac{104}{52.8}$

$x = 2\text{ ft}$

311. 1.8 mg/L + 0.9 mg/L = 2.7 mg/L

312. 23 mg/L × 0.98 MGD × 8.34 lb/gal = 18.8 lb/d

313. $\frac{60\text{ lb/d}}{0.65} = 92.3\text{ lb/d hypochlorite}$

314. $\frac{51\text{ lb/d}}{8.34\text{ lb/gal}} = 6.1\text{ gpd}$

315. $x$ mg/L + 0.6 mg/L = 3.1 mg/L

$x$ = 3.1 – 0.6 = 2.5 mg/L

316. $\frac{30\text{ lb} \times 0.65}{(66\text{ gal} \times 8.34\text{ lb/gal}) + (30\text{ lb} \times 0.65)} \times 100$

$\frac{30.65\text{ lb}}{550.4\text{ lb} + 19.5\text{ lb}} \times 100$

$\frac{30.65\text{ lb}}{569.9\text{ lb}} \times 100 = 5.4\%$

317. 1620 gpm × 1440 min/d = 2,332,800 gpd

2.8 mg/L × 2.332 MGD × 8.34 lb/gal = 54.5 lb/d

318. 2.8 mg/L × 1.33 MGD × 8.34 lb/gal = 12,500 mg/L × $x$ MGD × 8.34 lb/gal

$x = \frac{2.8 \times 1.33 \times 8.34}{12{,}500 \times 8.34}$

$x$ = 0.0002979 MGD

$x$ = 297.9 gpd

319. Volume (gal) = 0.785 × 0.67 × 0.67 × 1600 ft × 7.48 gal/ft$^3$ = 4217 gal

60 mg/L × 0.004217 MG × 8.34 lb/gal = 2.1 lb

320. $x$ mg/L × 2.11 MGD × 8.34 lb/gal = 3 lb/d

$$x = \frac{3}{2.11 \times 8.34}$$

$x$ = 0.17 mg/L

0.6 mg/L – 0.5 mg/L = 0.1

Chlorination is assumed to be at the breakpoint.

321. $$\frac{\left[70 \text{ gal} \times 8.34 \text{ lb/gal} \times (12/100)\right] + \left[250 \text{ gal} \times 8.34 \text{ lb/gal} \times (2/100)\right]}{(70 \text{ gal} \times 8.34 \text{ lb/gal}) + (250 \text{ gal} \times 8.34 \text{ lb/gal})} \times 100$$

$$\frac{70 \text{ lb} + 41.7}{584 + 2085} \times 100$$

$$\frac{111.7 \text{ lb}}{2669 \text{ lb}} \times 100 = 4.2\%$$

322. $$\frac{310 \text{ lb}}{34 \text{ lb/d}} = 9.1 \text{ d}$$

323. 44,115,670 gal – 43,200,000 gal = 915,670 gal

$x$ mg/L × 0.915 MGD × 8.34 lb/gal = 18 lb/d

$$x = \frac{18}{0.915 \times 8.34}$$

$x$ = 2.4 mg/L

324. $$\frac{32 \text{ lb/d}}{0.60} = 53.3 \text{ lb/d hypochlorite}$$

325. $$\frac{2{,}666{,}000 \text{ gal}}{7 \text{ d}} = 380{,}857 \text{ gpd}$$

4 in. ÷ 12 in./ft = 0.33 ft

$$\frac{0.785 \times 4 \text{ ft} \times 4 \text{ ft} \times 3.33 \text{ ft} \times 7.48 \text{ gal/ft}^3}{7 \text{ d}} = 45 \text{ gpd}$$

$x$ mg/L × 0.380 MGD × 8.34 lb/gal = 20,000 mg/L × 0.000026 × 8.34

$$x = \frac{20{,}000 \times 0.000026 \times 8.34}{0.380 \times 8.34}$$

$x$ = 1.37 mg/L

326. Chlorine dose = 3.0 mg/L

3.0 mg/L × 3.35 MGD × 8.34 lb/gal = 83.8 lb/d

327. $$\frac{\left[12 \text{ gal} \times (12/100)\right] + \left[50 \text{ gal} \times (1/100)\right]}{12 \text{ gal} + 50 \text{ gal}} \times 100 =$$

$$\frac{1.44 \text{ gal} + 0.5 \text{ gal}}{62 \text{ gal}} \times 100 =$$

$$\frac{1.94 \text{ gal}}{62 \text{ gal}} \times 100 = 3.1\%$$

328. 72 lb/d = $x$/0.65

$72 \times 0.65 = x$

46.8 lb/d = $x$

$x$ mg/L × 1.88 MGD × 8.34 lb/gal = 46.8 lb/d

$$x = \frac{46.8}{1.88 \text{ MGD} \times 8.34}$$

$x$ = 2.98 mg/L

329. 400 gpm × 1440 min/d = 576,000 gpd (0.576 MGD)

2.6 mg/L × 0.576 MGD × 8.34 lb/gal = 30,000 mg/L × $x$ MGD × 8.34 lb/gal

$$x = \frac{2.6 \times 0.576 \times 8.34}{30,000 \times 8.34}$$

$x$ = 49.9 gpd

330. $$\frac{0.785 \times 3 \text{ ft} \times 3 \text{ ft} \times 4.08 \text{ ft} \times 7.48 \text{ gal/ft}^3}{92 \text{ gpd}} = 2.3 \text{ d}$$

331. $$2 = \frac{x \text{ lb}}{(80 \text{ gal} \times 8.34 \text{ lb/gal}) + x \text{ lb}} \times 100$$

$$2 = \frac{100\,x}{667.2 + x}$$

$$667.2 + x = \frac{100\,x}{2}$$

$667.2 + x = 50x$

$667.2 = 49x$

$$x = \frac{667.2}{49}$$

$$x = 13.7 \text{ lb}$$

$$= \frac{13.7 \text{ lb}}{0.65}$$

$$= 21.1 \text{ lb hypochlorite}$$

332. $$\frac{32 \text{ lb/d}}{24 \text{ hr/d}} = 1.33 \text{ lb/hr chlorine used}$$

140 hr of operation → 1.33 lb/hr × 140 hr = 186.2 lb

333. 50 lb/d × 30 d = 1500 lb

$$\frac{1500 \text{ lb}}{150 \text{ lb/cylinder}} = 10 \text{ cylinders required}$$

334. 2.6% = 26,000 mg/L

335. 6600 mg/L = 0.67%

336. 29% = 290,000 mg/L

337. $$\frac{22 \text{ lb}}{1 \text{ MG} \times 8.34 \text{ lb/gal}} = \frac{22 \text{ lb}}{8.34 \text{ mil lb}} = \frac{2.64 \text{ lb}}{1 \text{ mil lb}} = 2.64 \text{ mg/L}$$

338. $1.6\ \text{mg/L} = \dfrac{1.6\ \text{lb}}{1\ \text{mil lb}} = \dfrac{1.6\ \text{lb}}{\dfrac{1\ \text{mil lb}}{8.34\ \text{lb/gal}}} = \dfrac{1.6\ \text{lb}}{0.12\ \text{MG}} = \dfrac{13.3}{1\ \text{MG}}$

339. $\dfrac{25\ \text{lb}}{1\ \text{MG} \times 8.34\ \text{lb/gal}} = \dfrac{25\ \text{lb}}{8.34\ \text{mil lb}} = \dfrac{2.99\ \text{lb}}{1\ \text{mil lb}} = 2.99\ \text{mg/L}$

340.

| Element | Atoms | | Atomic Weight | Molecular Weight |
|---|---|---|---|---|
| H | 2 | × | 1.008 | 2.016 |
| Si | 1 | × | 28.06 | 28.06 |
| F | 6 | × | 19.00 | 114.00 |
| Molecular weight | | | | 144.076 |

$$\frac{114.00}{144.076} \times 100 = 79.1\%$$

341.

| Element | Atoms | | Atomic Weight | Molecular Weight |
|---|---|---|---|---|
| Na | 1 | × | 22.997 | 22.997 |
| F | 1 | × | 19.00 | 19.00 |
| Molecular weight | | | | 41.997 |

$$\frac{19.00}{41.997} \times 100 = 45.2\%$$

342. $\dfrac{1.6\ \text{mg/L} \times 0.98\ \text{MG} \times 8.34\ \text{lb/gal}}{\dfrac{98}{100} \times \dfrac{60.6}{100}}$

$$\frac{13.1}{0.98 \times 0.606} = \frac{13.1}{0.59} = 22.2\ \text{lb/d}\ Na_2SiF_6$$

343. $\dfrac{1.4\ \text{mg/L} \times 1.78\ \text{MGD} \times 8.34\ \text{lb/gal}}{98/100 \times 60.6/100} = 35.2\ \text{lb/d}\ Na_2SiF_6$

$0.98 \times 0.606 = 0.59$

344. $\dfrac{1.4\ \text{mg/L} \times 2.880\ \text{MGD} \times 8.34\ \text{lb/gal}}{0.8\ \text{lb}} = 42.1\ \text{lb/d}\ Na_2SiF_6$

345. $\dfrac{1.1\ \text{mg/L} \times 3.08\ \text{MGD} \times 8.34\ \text{lb/gal}}{0.45\ \text{lb}} = 62.8\ \text{lb/d NaF}$

346. $1.2\ \text{mg/L} - 0.08\ \text{mg/L} = 1.13$

$$\frac{1.13\ \text{mg/L} \times 0.810\ \text{MGD} \times 8.34\ \text{lb/gal}}{0.45\ \text{lb}} = 169\ \text{lb/d NaF}$$

347. $\dfrac{91\ \text{lb} \times (98/100)}{(55\ \text{gal} \times 8.34\ \text{lb/gal}) + [9\ \text{lb} \times (98/100)]} \times 100$

$$\frac{8.82}{4.59 + 8.82} \times 100 = 1.9\%\ \text{strength NaF}$$

348. $$\frac{20 \text{ lb}}{(80 \text{ gal} \times 8.34 \text{ lb/gal}) + 20 \text{ lb}} \times 100$$

$$\frac{20 \text{ lb}}{667.2 + 20 \text{ lb}} \times 100$$

$$\frac{20}{687.2} \times 100 = 2.9 \text{ NaF}$$

349. $$1.4 = \frac{x \text{ lb} \times (98/100)}{(220 \text{ gal} \times 8.34 \text{ lb/gal}) + [x \text{ lb} \times (98/100)]} \times 100$$

$$1.4 = \frac{0.98x}{1835 + 0.98x} \times 100$$

$$1.4 = \frac{98x}{1835 + 0.98x}$$

$1.4 \times (1835 + 0.98x) = 98x$

$2569 + 137x = 98x$

$2569 = 96.63x$

$x = 26.6$ lb NaF

350. $$\frac{11 \text{ lb} \times (98/100)}{(60 \text{ gal} \times 8.34 \text{ lb/gal}) + [11 \text{ lb} \times (98/100)]} \times 100 =$$

$$\frac{10.78}{500 + 10.8} \times 100 = 21\% \text{ strength NaF}$$

$500 + 10.8$

351. $$3 = \frac{x \text{ lb} \times (98/100)}{(160 \text{ gal} \times 8.34 \text{ lb/gal}) + [x \text{ lb} \times (98/100)]} \times 100$$

$$3 = \frac{0.98x}{1334 + 0.98x} \times 100$$

$$3 = \frac{98x}{1334 + 0.98x}$$

$3(1334 + 0.98x) = 98x$

$1334 + 2.94x = 98x$

$1334 = 98x - 2.94x$

$1334 = 95.06x$

$x = 14$ lb NaF

352. 1.2 mg/L $\times$ 4.23 MGD $\times$ 8.34 lb/gal = 240,000 mg/L $\times x \times$ 8.34 lb/gal $\times$ 1.2 $\times$ (80/100)

$$\frac{1.2 \times 4.23 \times 8.34}{240{,}000 \times 8.34 \times 1.2 \times 0.800} = x \text{ MGD}$$

$x = 0.0000217$ MGD

$x = 21.7$ gpd

353. 1.2 mg/L × 3.1 MGD × 8.34 lb/gal = 220,000 mg/L × $x$ ×9.7 lb/gal × (80/100)

$$\frac{1.2 \times 3.1 \times 8.34}{220{,}000 \times 9.7 \times 0.800} = x \text{ MGD}$$

$x$ = 0.0000199

$x$ = 19.9 gpd

354. 1.8 mg/L – 0.09 mg/L = 1.71 mg/L

1.71 mg/L × 0.91 MGD × 8.34 lb/gal = 22,000 mg/L × $x$ × 8.34 lb/gal × (46.10/100)

$$\frac{1.71 \times 0.91 \times 8.34}{22{,}000 \times 8.34 \times 0.4610} = x \text{ MGD}$$

0.0001543 MGD = $x$ or 154.3 gpd

355. 1.6 mg/L × 1.52 MGD × 8.34 lb/gal = 24,000 mg/L × $x$ × 8.34 lb/gal × (45.25/100)

$$\frac{1.6 \times 1.52 \times 8.34}{24{,}000 \times 8.34 \times 0.4575} = x \text{ MGD}$$

0.0002239 MGD = $x$

$x$ = 223.9 gpd

356. $$\frac{80 \text{ gpd} \times 3785 \text{ mL/gal}}{1440 \text{ min/d}} = 210.3 \text{ mL/min}$$

357. 1.0 mg/L × 2.78 MGD × 8.34 = 250,000 mg/L × $x$ MGD × 9.8 lb/gal × (80/100)

$$\frac{1.0 \times 2.78 \times 8.34}{250{,}000 \times 9.8 \times 0.80} = x \text{ MGD}$$

0.0000118 MGD = $x$ = 11.8 gpd

$$\frac{11.8 \text{ gpd} \times 3785 \text{ mL/gal}}{1440 \text{ min/d}} = 31 \text{ mL/min}$$

358. $$\frac{x \text{ mg/L} \times 1.52 \text{ MGD} \times 8.34 \text{ lb/gal}}{(95/100) \times (61/100)} = 40 \text{ lb/d}$$

$x$ × 1.52 × 8.34 = 40 × 0.98 × 0.61

$$x = \frac{40 \times 0.98 \times 0.61}{1.52 \times 8.34}$$

$$x = \frac{23.9}{12.7}$$

$x$ = 1.89 mg/L

359. $$\frac{x \text{ mg/L} \times 0.33 \text{ MGD} \times 8.34 \text{ lb/gal}}{(98/100) \times (45.25/100)} = 6 \text{ lb/d}$$

$x$ × 0.33 × 8.34 = 6 × 0.98 × 0.4525

$$x = \frac{6 \times 0.98 \times 0.4525}{0.33 \times 8.34}$$

$x$ = 0.97 mg/L

360. $x$ mg/L × 3.85 MGD × 8.34 lb/gal = 200,000 mg/L × 0.000032 × 9.8 lb/gal × (80/100)

$$x = \frac{200{,}000 \times 0.000032 \times 9.8 \times 0.80}{3.85 \times 8.34}$$

$x$ = 1.6 mg/L

361. $x \times 1.92$ MGD $\times$ 8.34 lb/gal = 110,000 mg/L $\times$ 0.000028 MGD $\times$ 9.10 lb/gal $\times$ (80/100)

$$x = \frac{110,000 \times 0.000028 \times 9.10 \times 0.80}{1.92 \times 8.34}$$

$x = 1.4$ mg/L

362. $x \times 2.73$ MGD $\times$ 8.34 lb/gal = 30,000 mg/L $\times$ 0.000110 $\times$ 8.34 lb/gal $\times$ (45.25/100)

$$x = \frac{30,000 \times 0.000110 \times 8.34 \times 0.4525}{2.73 \times 8.34}$$

$x = 0.55$ mg/L

363. $$\frac{\left[600 \text{ lb} \times (15/100)\right] + \left[2600 \text{ lb} \times (25/100)\right]}{600 \text{ lb} + 2600 \text{ lb}} \times 100 =$$

$$\frac{90 \text{ lb} + 650 \text{ lb}}{3200 \text{ lb}} \times 100 = 23\%$$

364. [900 lb $\times$ (25/100)] + [300 lb $\times$ (15/100)] = 1200 lb $\times$ $x$/100

225 lb + 45 lb = 1200 $\times$ $x$/100

270 = 12$x$

270/12 = $x$ = 22.5

365. $$\frac{\left[400 \text{ gal} \times 9.4 \text{ lb/gal} \times (16/100)\right] + \left[2200 \times 9.10 \text{ lb/gal} \times (26/100)\right]}{(400 \text{ gal} \times 19.4 \text{ lb/gal}) + (2200 \times 9.10 \text{ lb/gal})} \times 100 =$$

$$\frac{601.6 \text{ lb} + 4404.4 \text{ lb}}{3760 \text{ lb} + 20,020 \text{ lb}} \times 100 =$$

$$\frac{5006}{23,780} = 21.1\%$$

366. $$\frac{\left[325 \text{ gal} \times 9.06 \text{ lb/gal} \times (11/100)\right] + \left[1100 \text{ gal} \times 9.8 \text{ lb/gal} \times (20/100)\right]}{(325 \text{ gal} \times 9.06 \text{ lb/gal}) + (1100 \times 9.8 \text{ lb/gal})} \times 100 =$$

$$\frac{324 \text{ lb} + 2156}{2944.5 \text{ lb} + 10,780 \text{ lb}} \times 100 =$$

$$\frac{2480 \text{ lb}}{13,724.5 \text{ lb}} \times 100 = 18.1\%$$

367. Density = 8.34 lb/gal $\times$ 1.075 = 8.97

$$\frac{\left[220 \text{ gal} \times 8.97 \text{ lb/gal} \times (10/100)\right] + \left[1600 \times 9.5 \text{ lb/gal} \times (15/100)\right]}{(220 \text{ gal} \times 8.97 \text{ lb/gal}) + (1600 \times 9.5 \text{ lb/gal})} \times 100 =$$

$$\frac{197.3 \text{ lb} + 2280 \text{ lb}}{1973 \text{ lb} + 15,200 \text{ lb}} \times 100 =$$

$$\frac{2477.3 \text{ lb}}{17,173 \text{ lb}} \times 100 = 14.4\%$$

368. 2.9000 = 29,000 mg/L

369. Molecular weight = $2 \times 1.008 = 2.016$

$$\begin{aligned} 1 \times 28.06 &= 28.06 \\ 6 \times 19.00 &= \underline{114.00} \\ &\phantom{=}\ 144.076 \end{aligned}$$

$$\frac{114.00}{144.076} \times 100 = 79.1\%$$

370. $$\frac{27\ \text{lb}}{1\ \text{MG} \times 8.34\ \text{lb/gal}} = \frac{27\ \text{lb}}{8.34\ \text{mil lb}} \times \frac{3.24}{1\ \text{mil lb}} = 3.24\ \text{mg/L}$$

371. $$\frac{1.6\ \text{mg/L} \times 2.111\ \text{MGD} \times 8.34\ \text{lb/gal}}{(98/100) \times (61.2/100)} = 47\ \text{lb/d}$$

372. Molecular weight of NaF = 41.997

$$\frac{19.00}{41.997} \times 100 = 45.2\%$$

373. $$\frac{80\ \text{lb} \times (98/100)}{(600\ \text{gal} \times 8.34\ \text{lb/gal}) + [80\ \text{lb} \times (98/100)]} \times 100 =$$

$$\frac{78.4\ \text{lb}}{5004\ \text{lb} + 78.4\ \text{lb}} \times 100 =$$

$$\frac{78.4}{5082.4} \times 100 = 1.5\%$$

374. 28,000 mg/L = 2.8%

375. $$\frac{80\ \text{gpd} \times 3785\ \text{mL/gal}}{1440\ \text{min/d}} = 210\ \text{mL/min}$$

376. $$\frac{1.5\ \text{mg/L} \times 2.45\ \text{MGD} \times 8.34\ \text{lb/gal}}{(98/100) \times (45.25/100)} = 156\ \text{lb/d}$$

377. $$3 = \frac{x\ \text{lb} \times (98/100)}{(600\ \text{gal} \times 8.34\ \text{lb/gal}) + [x\ \text{lb} \times (98/100)]} \times 100$$

$$3 = \frac{0.98x}{5004\ \text{lb} + 0.98x} \times 100$$

$$3 = \frac{98x}{5004 + 0.98x}$$

$3 \times (5004 + 0.98x) = 98x$

$15.012 + 2.94x = 98x$

$15.012 = 95.06x$

$x = 158$ lb

378 $1.4\ \text{mg/L} \times 4.11 \times 8.34\ \text{lb/gal} = 210{,}000\ \text{mg/L} \times x\ \text{MGD} \times 8.34\ \text{lb/gal} \times 1.3 \times (80/100)$

$$\frac{1.4 \times 4.11 \times 8.34}{210{,}000 \times 8.34 \times 1.3 \times 0.8} = x\ \text{MGD}$$

$0.0000262\ \text{MGD} = x = 26.2$ gpd

379. $$\frac{30 \text{ lb} \times (98/100)}{(140 \text{ gal} \times 8.34 \text{ lb/gal}) + [30 \text{ lb} \times (98/100)]} \times 100 =$$

$$\frac{29.4 \text{ lb}}{1167.8 \text{ lb} + 29.4} \times 100 =$$

$$\frac{29.4}{1197.2} \times 100 = 2.45\%$$

380. 1.4 mg/L – 0.09 mg/L = 1.31 mg/L

$$\frac{1.31 \text{ mg/L} \times 1.88 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.44} = 46.7 \text{ lb/d NaF}$$

381. 1.3 mg/L × 2.8 MGD × 8.34 lb/gal = 200,000 × $x$ MGD × 9.8 lb/gal × (80/100)

$$\frac{1.3 \times 2.8 \times 8.34}{200{,}000 \times 9.8 \times 0.80} \times \text{MGD}$$

$x$ = 0.0000193 MGD

$x$ = 19.3 gpd

382. $$\frac{[500 \text{ lb} \times (15/100)] + [1600 \text{ lb} \times (20/100)]}{500 + 1600 \text{ lb}} \times 100 =$$

$$\frac{75 \text{ lb} + 320 \text{ lb}}{2100 \text{ lb}} \times 100 =$$

$$\frac{395 \text{ lb}}{2100 \text{ lb}} \times 100 = 18.8\%$$

383. $$\frac{x \text{ mg/L} \times 1.10 \text{ MGD} \times 8.34 \text{ lb/gal}}{(98/100) \times (61.1/100)} = 41 \text{ lb/d}$$

$x$ × 1.10 × 8.34 = 41 × 0.98 × 0.611

$$x = \frac{41 \times 0.98 \times 0.611}{1.10 \times 8.34}$$

$x$ = 2.7 mg/L

384. 1400 gpm × 1440 min/d = 2,016,000 gpd = 2.016 MGD

$x$ mg/L × 2.016 flow × 8.34 lb/gal = 110,000 mg/L × 0000.40 MGD × 9.14 lb/gal

$$x = \frac{110{,}000 \times 0.000040 \times 9.14 \times 0.8}{2.016 \times 8.34}$$

$x$ = 1.92 mg/L

385. $$\frac{[235 \text{ gal} \times 9.14 \text{ lb/gal} \times (10/100)] + [600 \text{ gal} \times 9.8 \text{ lb/gal} \times (20/100)]}{(235 \text{ gal} \times 9.14 \text{ lb/gal}) + (600 \text{ gal} \times 9.8 \text{ lb/gal})} \times 100 =$$

$$\frac{215 \text{ lb} + 1176 \text{ lb}}{2147.9 \text{ lb} + 5880 \text{ lb}} \times 100 =$$

$$\frac{1391}{8027.9} \times 100 = 17.3\%$$

386. 1.1 mg/L × 2.88 MGD × 8.34 lb/gal = 200,000 mg/L × $x$ MGD × 9.8 lb/gal × (80/100)

$$\frac{1.1 \times 2.88 \times 8.34}{200{,}000 \times 9.8 \times 0.8} = x \text{ MGD}$$

$x$ = 0.0000168 MGD

$x$ = 16.8 gpd

$$\frac{16.8 \text{ gpd} \times 3785 \text{ mL/gal}}{1440 \text{ min/d}} = 44.2 \text{ mL/min}$$

387. Density = 8.34 lb/gal × 1.115 = 9.3 lb/gal

$$\frac{\left[131 \text{ gal} \times 9.3 \text{ lb/gal} \times (9/100)\right] + \left[900 \text{ gal} \times 9.4 \text{ lb/gal} \times (15/100)\right]}{(131 \text{ gal} \times 9.3 \text{ lb/gal}) + (900 \text{ gal} \times 9.4 \text{ lb/gal})} \times 100 =$$

$$\frac{109.6 + 1269 \text{ lb}}{1218 \text{ lb} + 8460 \text{ lb}} \times 100 =$$

$$\frac{1378.6}{9678} \times 100 = 14.2\%$$

388. $x$ mg/L × 2.90 × 8.34 lb/gal = 50,000 mg/L × 0.000120 × 8.34 lb/gal × (45.25/100)

$$x = \frac{50{,}000 \times 0.000120 \times 8.34 \times 0.4525}{2.90 \text{ MGD} \times 8.34}$$

$x$ = 0.94 mg/L F

0.94 mg/L F added + 0.2 mg/L in raw water = 0.96 in finished water

389. $$\frac{x \text{ mg/L}}{50.45} = \frac{39 \text{ mg/L}}{20.04}$$

$$x = \frac{39 \times 50.45}{20.04}$$

$x$ = 98.2 mg/L calcium as $CaCO_3$

390. $$\frac{x \text{ mg/L}}{50.45} = \frac{33 \text{ mg/L}}{12.16}$$

$$x = \frac{33 \times 50.45}{12.16}$$

$x$ = 136 mg/L magnesium as $CaCO_3$

391. $$\frac{x \text{ mg/L}}{50.045} = \frac{18 \text{ mg/L}}{20.04}$$

$$x = \frac{18 \times 50.045}{20.04}$$

$x$ = 44.9 mg/L calcium as $CaCO_3$

392. 75 mg/L + 91 mg/L = 166 mg/L as $CaCO_3$

393. $$\frac{x \text{ mg/L}}{50.045} = \frac{30 \text{ mg/L}}{20.04}$$

$$x = \frac{30 \times 50.045}{20.04}$$

$x$ = 74.9 mg/L calcium as $CaCO_3$

$$\frac{x \text{ mg/L}}{50.045} = \frac{10 \text{ mg/L}}{12.16}$$

$$x = \frac{10 \times 50.045}{12.16}$$

$x$ = 41 mg/L magnesium as $CaCO_3$

Total hardness mg/L as $CaCO_3$ = 74.9 mg/L + 41 mg/L = 115.9 mg/L

394. $$\frac{x \text{ mg/L}}{50.045} = \frac{21 \text{ mg/L}}{20.04}$$

$$x = \frac{21 \times 50.045}{20.04}$$

$x$ = 52.4 mg/L calcium as $CaCO_3$

$$\frac{x \text{ mg/L}}{50.045} = \frac{15 \text{ mg/L}}{12.16}$$

$$x = \frac{15 \times 50.045}{12.16}$$

$x$ = 61.7 mg/L magnesium as $CaCO_3$

52.4 mg/L + 61.7 mg/L = 114.1 mg/L total hardness as $CaCO_3$

395. Total hardness (mg/L) as $CaCO_3$ = carbonate hardness (mg/L) = 121 mg/L as $CaCO_3$ = carbonate hardness; the water has no noncarbonate hardness

396. 122 mg/L = 105 mg/L + $x$ mg/L
122 mg/L – 105 mg/L = $x$ mg/L
Noncarbonate hardness 17 mg/L = $x$
Carbonate hardness is 105 mg/L

397. 116 mg/L = 91 mg/L + $x$ mg/L
116 mg/L – 91 mg/L = $x$ mg/L
Noncarbonate hardness 25 mg/L = $x$
Carbonate hardness is 91 mg/L

398. Alkalinity is greater than total hardness; therefore, all the hardness is carbonate hardness
99 mg/L as $CaCO_3$ = carbonate hardness

399. 121 mg/L = 103 mg/L + mg/L
121 mg/L – 103 mg/L = $x$ mg/L
Noncarbonate hardness 18 mg/L = $x$
Carbonate hardness is 103 mg/L

400. $$\text{Phenolphthalein alkalinity } \left(\text{mg/L as } CaCO_3\right) = \frac{A \times N \times 50{,}000}{\text{mL of sample}}$$

$$= \frac{2.0 \text{ mL} \times 0.02\ N \times 50{,}000}{100 \text{ mL}}$$

= 20 mg/L as $CaCO_3$ phenolphthalein alkalinity

401. $$\frac{1.4 \text{ mL} \times 0.02\ N \times 50{,}000}{100 \text{ mL}} = 14 \text{ mg/L}$$

402. $$\frac{0.3\text{ mL} \times 0.02\,N \times 50{,}000}{100\text{ mL}} = 3\text{ mg/L}$$

$$\text{Total alkalinity} = \frac{6.7\text{ mL} \times 0.02\,N \times 50{,}000}{100\text{ mL}} = 67\text{ mg/L}$$

403. Phenolphthalein alkalinity = 0 mg/L

$$\text{Total alkalinity} = \frac{6.9\text{ mL} \times 0.02\,N \times 50{,}000}{100\text{ mL}} = 69\text{ mg/L as CaCO}_3$$

404. $$\text{Phenolphthalein alkalinity} = \frac{0.5\text{ mL} \times 0.02\,N \times 50{,}000}{100\text{ mL}} = 5\text{ mg/L as CaCO}_3$$

$$\text{Total alkalinity} = \frac{5.7\text{ mL} \times 0.02\,N \times 50{,}000}{100\text{ mL}} = 57\text{ mg/L as CaCO}_3$$

405. $$\begin{aligned}\text{Bicarbonate alkalinity} &= T - 2P\\ &= 51\text{ mg/L} - (2 \times 8\text{ mg/L})\\ &= 51\text{ mg/L} - 16\text{ mg/L}\\ &= 35\text{ mg/L as CaCO}_3\end{aligned}$$

$$\begin{aligned}\text{Carbonate alkalinity} &= 2P\\ &= 2 \times 8\text{ mg/L}\\ &= 16\text{ mg/L as CaCO}_3\end{aligned}$$

Hydroxide alkalinity = 0

406. Bicarbonate alkalinity = $T$

= 67 mg/L as $CaCO_3$

Carbonate alkalinity = 0

Hydroxide alkalinity = 0

407. Bicarbonate alkalinity = 0

$$\begin{aligned}\text{Carbonate alkalinity} &= 2T - 2P\\ &= (2 \times 23\text{ mg/L}) - (2 \times 12\text{ mg/L})\\ &= 46\text{ mg/L} - 24\text{ mg/L}\\ &= 22\text{ mg/L as CaCO}_3\end{aligned}$$

$$\begin{aligned}\text{Hydroxide alkalinity} &= 2P - T\\ &= (2 \times 12\text{ mg/L}) - 23\text{ mg/L}\\ &= 24\text{ mg/L} - 23\text{ mg/L}\\ &= 1\text{ mg/L as CaCO}_3\end{aligned}$$

408. $$\begin{aligned}\text{Phenolphthalein alkalinity} &= \frac{1.3\text{ mL} \times 0.02\,N \times 50{,}000}{100\text{ mL}}\\ &= 13\text{ mg/L as CaCO}_3\end{aligned}$$

$$\text{Total alkalinity} = \frac{5.3\text{ mL} \times 0.02\,N \times 50{,}000}{100\text{ mL}}$$

$$= 53\text{ mg/L as CaCO}_3$$

$$\text{Bicarbonate alkalinity} = T - 2P$$

$$= 51\text{ mg/L} - (2 \times 13\text{ mg/L})$$

$$= 51\text{ mg/L} - 26\text{ mg/L}$$

$$= 25\text{ mg/L as CaCO}_3$$

$$\text{Carbonate alkalinity} = 2P$$

$$= 2 \times 13\text{ mg/L}$$

$$= 26\text{ mg/L as CaCO}_3$$

Hydroxide alkalinity = 0

409. $$\text{Phenolphthalein alkalinity} = \frac{1.5\text{ mL} \times 0.02\,N \times 50{,}000}{100\text{ mL}}$$

$$= 15\text{ mg/L as CaCO}_3$$

$$\text{Total alkalinity} = \frac{2.9\text{ mL} \times 0.02\,N \times 50{,}000}{100\text{ mL}}$$

$$= 29\text{ mg/L as CaCO}_3$$

From the alkalinity table:

Bicarbonate alkalinity = 0

$$\text{Carbonate alkalinity} = 2P$$

$$= 2 \times 15\text{ mg/L}$$

$$= 30\text{ mg/L as CaCO}_3$$

Hydroxide alkalinity = 0

410. $$A = CO_2\ (\text{mg/L}) \times 56/44$$

$$= 8\text{ mg/L} \times 56/44$$

$$= 10\text{ mg/L}$$

$$B = \text{Alkalinity}\ (\text{mg/L}) \times 56/100$$

$$= 130\text{ mg/L} \times 56/100$$

$$= 73\text{ mg/L}$$

$C = 0$

$$D = MG^{2+}\ (\text{mg/L}) \times 56/24.3$$

$$= 22\text{ mg/L} \times 56/24.3$$

$$= 51\text{ mg/L}$$

$$\text{Quicklime dosage (mg/L)} = \frac{10 \text{ mg/L} + 73 \text{ mg/L} + 0 + 51 \text{ mg/L} \times 1.15}{0.90}$$

$$= \frac{134 \text{ mg/L} \times 1.15}{0.90}$$

$$= 171 \text{ mg/L CaO}$$

411. $A = CO_2 \text{ (mg/L)} \times (74/44)$

$$= 5 \text{ mg/L} \times (74/44)$$

$$= 8 \text{ mg/L}$$

$B = \text{Alkalinity (mg/L)} \times (74/100)$

$$= 164 \text{ mg/L} \times (74/100)$$

$$= 121 \text{ mg/L}$$

$C = 0$

$D = MG^{2+} \text{ (mg/L)} \times (74/24.3)$

$$= 17 \text{ mg/L} \times (74/24.3)$$

$$= 52 \text{ mg/L}$$

$$\text{Hydrated lime dosage (mg/L)} = \frac{8 \text{ mg/L} + 121 \text{ mg/L} + 0 + 52 \text{ mg/L} \times 1.15}{0.90}$$

$$= \frac{181 \text{ mg/L} \times 1.15}{0.90}$$

$$= 231 \text{ mg/L Ca(OH)}_2$$

412. $A = CO_2 \text{ (mg/L)} \times (74/44)$

$$= 6 \text{ mg/L} \times (74/44)$$

$$= 10 \text{ mg/L}$$

$B = \text{Alkalinity (mg/L)} \times (24/100)$

$$= 110 \text{ mg/L} \times (74/100)$$

$$= 81 \text{ mg/L}$$

$C = 0$

$D = MG^{2+} \text{ (mg/L)} \times (74/24.3)$

$$= 12 \text{ mg/L} \times (74/24.3)$$

$$= 37 \text{ mg/L}$$

$$\text{Hydrated lime dosage (mg/L)} = \frac{10 \text{ mg/L} + 81 \text{ mg/L} + 0 + 37 \text{ mg/L} \times 1.15}{0.90}$$

$$= \frac{128 \text{ mg/L} \times 1.15}{0.90}$$

$$= 164 \text{ mg/L } Ca(OH)_2$$

413. $A = \text{Carbon dioxide (mg/L)} \times (56/44)$

$$= 9 \text{ mg/L} \times (56/44)$$

$$= 11 \text{ mg/L}$$

$B = \text{Alkalinity (mg/L)} \times (56/100)$

$$= 180 \text{ mg/L} \times (56/100)$$

$$= 101 \text{ mg/L}$$

$C = 0$

$D = \text{MG}^{2+} \text{ (mg/L)} \times (56/24.3)$

$$= 18 \text{ mg/L} \times (56/24.3)$$

$$= 41 \text{ mg/L}$$

$$\text{Quicklime dosage (mg/L)} = \frac{11 \text{ mg/L} + 101 \text{ mg/L} + 0 + 41 \text{ mg/L} \times 1.15}{0.90}$$

$$= \frac{153 \text{ mg/L} \times 1.15}{0.90}$$

$$= 196 \text{ mg/L CaO}$$

414. 260 mg/L = 169 mg/L + $x$ mg/L
260 mg/L – 169 mg/L = $x$ mg/L
$x$ = 91 mg/L
Soda ash (mg/L) = 91 mg/L × (106/100) = 96 mg/L

415. Noncarbonate hardness: 240 mg/L = 111 mg/L + $x$ mg/L
240 mg/L – 111 mg/L = $x$ mg/L = 129 mg/L
Soda ash (mg/L) = 129 mg/L × (106/100) = 137 mg/L

416. Noncarbonate hardness: 264 mg/L = 170 mg/L + $x$ mg/L
264 mg/L – 170 mg/L = $x$ mg/L = 94 mg/L
Soda ash (mg/L) = 94 mg/L × (106/100) = 100 mg/L

417. 228 mg/L = 108 mg/L + $x$ mg/L
228 mg/L – 108 mg/L = $x$ mg/L = 120 mg/L
Soda ash (mg/L) = 120 mg/L × (106/100) = 127 mg/L

418. Excess lime (mg/L) = (8 mg/L + 130 mg/L + 0 + 66 mg/L) × 0.15 =
204 mg/L × 0.15 = 31 mg/L
Total carbon dioxide (mg/L) = 31 mg/L × (44/100) + 4 mg/L × (44/24.3) =
14 mg/L + 7 mg/L = 21 mg/L

419. Excess lime (mg/L) = (8 mg/L + 90 mg/L + 7 + 109 mg/L) × 0.15 =
213 mg/L × 0.15 = 32 mg/L
Total carbon dioxide (mg/L) = [32 mg/L × (44/74)] + [3 mg/L × (44/24.3)] =
19 mg/L + 5.4 mg/L = 24.4 mg/L

420. Excess lime (mg/L) = (7 mg/L + 109 mg/L + 3 + 52 mg/L) × 0.15 =
171 mg/L × 0.15 = 26 mg/L
Total carbon dioxide (mg/L) = [26 mg/L × (44/74)] + [5 mg/L × (44/24.3)] =
15.5 mg/L + 9 mg/L = 24.5 mg/L

421. Excess lime (mg/L) = (6 mg/L + 112 mg/L + 6 + 45 mg/L) × 0.15 =
169 mg/L × 0.15 = 26 mg/L
Total carbon dioxide (mg/L) = [26 mg/L × (44/74)] + [4 mg/L × (44/24.3)] =
15 mg/L + 7 mg/L = 22 mg/L

422. 200 mg/L × 2.47 MGD × 8.34 lb/gal = 4120 lb/d

423. 180 mg/L × 3.12 MGD × 8.34 lb/gal = 4684 lb/d

$$\frac{4684 \text{ lb/d}}{1440 \text{ min/d}} = 3.3 \text{ lb/min}$$

424. 60 mg/L × 4.20 MGD × 8.34 lb/gal = 2102 lb/d

$$\frac{2102 \text{ lb/d}}{24 \text{ hr/d}} = 87.5 \text{ lb/hr}$$

425. 130 mg/L × 1.85 MGD × 8.34 lb/gal = 2006 lb/d

$$\frac{2006 \text{ lb/d}}{1440 \text{ min/d}} = 1.4 \text{ lb/min}$$

426. 40 mg/L × 3.11 MGD × 8.34 lb/gal = 1038 lb/d

$$\frac{1038 \text{ lb/d}}{24 \text{ hr/d}} = 43 \text{ lb/hr}$$

$$\frac{43 \text{ lb/hr}}{60 \text{ min/hr}} = 0.7 \text{ lb/min}$$

427. 17.12 mg/L/gpg

$$\frac{211 \text{ mg/L}}{17.12 \text{ mg/L/gpg}} = 12.3 \text{ gpg}$$

428. 17.12 mg/L/gpg
12.3 mg/L × 17.12 mg/L/gpg = 211 mg/L

429. $$\frac{240 \text{ mg/L}}{17.12 \text{ mg/L/gpd}} = 14 \text{ gpg}$$

430. 14 gpg × 17.12 mg/L/gpg = 240 mg/L

431. 25,000 gr/ft$^3$ × 105 ft$^3$ = 2,625,000 gr

432. 0.785 × 6 ft × 6 ft × 4.17 ft
= 118 ft$^3$
= 25,000 gr/ft$^3$ × 118 ft$^3$
= 2,950,000 gr

433. 20,000 gr/ft$^3$ × 260 ft$^3$ = 5,200,000 gr

434. $0.785 \times 8\text{ft} \times 8\text{ ft} \times 5\text{ ft} = 251\text{ ft}^3$

$22{,}000\text{ gr/ft}^3 \times 251\text{ ft}^3 = 5{,}522{,}000\text{ gr}$

435. $\dfrac{2{,}210{,}000\text{ gr}}{18.1\text{ gpg}} = 122{,}099\text{ gal}$

436. $\dfrac{4{,}200{,}000\text{ gr}}{16.0\text{ gpg}} = 262{,}500\text{ gal}$

437. $\dfrac{270\text{ mg/L}}{17.12\text{ mg/L/gpg}} = 15.8\text{ gpg}$

$\dfrac{3{,}650{,}000\text{ gr}}{15.8\text{ gpg}} = 231{,}013\text{ gal}$

438. $21{,}000\text{ gr/ft}^3 \times 165\text{ ft}^3 = 3{,}465{,}000\text{ gr}$

$\dfrac{3{,}465{,}000\text{ gr}}{14.6\text{ gpg}} = 237{,}329\text{ gal}$

439. $0.785 \times 3\text{ ft} \times 3\text{ ft} \times 2.6\text{ ft} = 18.4\text{ ft}^3$

$22{,}000\text{ gr/ft}^3 \times 18.4\text{ ft}^3 = 404{,}800\text{ gr}$

$\dfrac{404{,}800\text{ gr}}{18.4\text{ gpg}} = 22{,}000\text{ gal}$

440. $\dfrac{575{,}000\text{ gal}}{25{,}200\text{ gph}} = 22.8\text{ hr of operation}$

441. $\dfrac{766{,}000\text{ gal}}{26{,}000\text{ gph}} = 29.5\text{ hr of operation}$

442. $230\text{ gpm} \times 60\text{ min/hr} = 13{,}800\text{ gph}$

$\dfrac{348{,}000\text{ gal}}{13{,}800\text{ gph}} = 25.2\text{ hr of operating time}$

443. $\dfrac{3{,}120{,}000\text{ gr}}{14\text{ gpg}} = 222{,}857\text{ gal}$

$200\text{ gpm} \times 60\text{ min/hr} = 12{,}000\text{ gph}$

$\dfrac{222{,}857\text{ gal}}{12{,}000\text{ gph}} = 18.6\text{ hr operating time}$

444. $\dfrac{3{,}820{,}000\text{ gr}}{11.6\text{ gpg}} = 329{,}310\text{ gal}$

$\dfrac{290{,}000\text{ gpd}}{24\text{ hr/d}} = 12{,}083\text{ gph}$

$\dfrac{329{,}310\text{ gal}}{12{,}083\text{ gph}} = 27.3\text{ hr operating time}$

445. $\dfrac{0.5\text{ lb salt} \times 2300\text{ kgr}}{\text{kgr removed}} = 1150\text{ lb salt required}$

446. $\dfrac{0.4\text{ lb salt} \times 1330\text{ kgr}}{\text{kgr removed}} = 532\text{ lb salt required}$

447. $\dfrac{410 \text{ lb salt}}{1.19 \text{ lb salt/gal brine}} = 345 \text{ gal of } 13\% \text{ brine}$

448. $\dfrac{420 \text{ lb salt}}{1.29 \text{ lb salt/gal brine}} = 326 \text{ gal of } 14\% \text{ brine}$

449. $\dfrac{0.5 \text{ lb salt} \times 1310 \text{ kgr}}{\text{kgr removed}} = 655 \text{ lb salt required}$

$$\frac{655 \text{ lb salt}}{1.09 \text{ lb salt/gal brine}} = 601 \text{ gal of } 12\% \text{ brine}$$

450. $\dfrac{x \text{ mg/L}}{50.045} = \dfrac{44 \text{ mg/L}}{20.04}$

$$x \text{ mg/L} = \frac{44 \text{ mg/L} \times 50.045}{20.04}$$

$x$ mg/L = 110 mg/L as $CaCO_3$

451. $\dfrac{1.8 \text{ mL} \times 0.02\,N \times 50{,}000}{100 \text{ mL}} = 18 \text{ mg/L as } CaCO_3$

452. $\dfrac{x \text{ mg/L}}{50.045} = \dfrac{31 \text{ mg/L}}{12.16}$

$$x = \frac{31 \times 50.045}{12.16} = 128 \text{ mg/L as } CaCO_3$$

453. $\dfrac{24 \text{ mg}}{12.16} = 1.97 \text{ meq}$

454. $A = 8 \text{ mg/L} \times (74/44)$

$= 13 \text{ mg/L}$

$B = 118 \text{ mg/L} \times (74/100)$

$= 87 \text{ mg/L}$

$C = 0$

$D = 12 \text{ mg/L} \times (74/24.3)$

$= 37 \text{ mg/L}$

$$\frac{13 \text{ mg/L} + 87 \text{ mg/L} + 0 + 37 \text{ mg/L} \times 1.15}{0.90}$$

$$\frac{137 \text{ mg/L} \times 1.15}{0.90} = 158 \text{ mg/L } Ca(OH)_2$$

455. Calcium hardness:

$$\frac{x \text{ mg/L}}{50.045} = \frac{31 \text{ mg/L}}{20.04}$$

$x$ = 77 mg/L Ca as $CaCO_3$

Magnesium hardness:

$$\frac{x \text{ mg/L}}{50.045} = \frac{11 \text{ mg/L}}{12.16}$$

$x$ = 45 mg/L Mg as $CaCO_3$

Total hardness (mg/L as $CaCO_3$) = 77 mg/L + 45 mg/L = 122 mg/L as $CaCO_3$

456. 101 mg/L as $CaCO_3$ = carbonate hardness

457. $A$ = 5 mg/L × (56/44) = 6 mg/L

$B$ = 156 mg/L × (56/100) = 87 mg/L

$C$ = 0 mg/L

$D$ = 11 mg/L × (56/24.3) = 25 mg/L

$$\text{Quicklime dosage } (\text{mg/L}) = \frac{(6 \text{ mg/L} + 87 \text{ mg/L} + 0 + 25 \text{ mg/L}) \times 1.15}{0.90}$$

$$\frac{118 \text{ mg/L} \times 1.15}{0.90} = 151 \text{ mg/L CaO}$$

## WASTEWATER CALCULATIONS (PROBLEMS 1 TO 574)

1. 4.9 MGD × 1 d/24 hr × 96 hr = 19.6 MG

$$\frac{4.3 \text{ ft} \times 5.8 \text{ ft} \times 28 \text{ in.}}{19.6 \text{ MG}} \times \frac{1 \text{ ft}}{12 \text{ in.}} = 3.0 \text{ ft}^3/\text{MG}$$

2. $$\frac{700 \text{ gpm}}{7.48 \text{ gal/ft}^3} = 93.6 \text{ ft}^3/\text{min}$$

$$\frac{93.6 \text{ ft}^3}{1 \text{ min}} \times \frac{1 \text{ min}}{60 \text{ s}} \times \frac{1}{1.4 \text{ ft} \times 1.7 \text{ ft}} = 0.7 \text{ ft/s}$$

3. $$\frac{1{,}200{,}000 \text{ gal}}{1 \text{ d}} \times \frac{1 \text{ d}}{24 \text{ hr}} \times \frac{1 \text{ hr}}{60 \text{ min}} = \frac{1{,}200{,}000 \text{ gal}}{1440 \text{ min/d}} = 833 \text{ gpm}$$

$$\frac{16 \text{ in.}}{12 \text{ in.}} = 1.4 \text{ ft} \qquad \frac{18 \text{ in.}}{12 \text{ in.}} = 1.6 \text{ ft}$$

$$\frac{883 \text{ gal}}{1 \text{ min}} \times \frac{1 \text{ ft}^3}{7.48 \text{ gal}} \times \frac{1 \text{ min}}{60 \text{ s}} = 1.97 \text{ ft}^3/\text{s}$$

$$\frac{1.97 \text{ ft}^3}{1 \text{ s}} \times \frac{1}{1.33 \text{ ft} \times 1.5 \text{ ft}} = 0.99 \text{ ft/s}$$

4. 12 ft × 10 ft × 6 ft × 7.48 gal/$ft^3$ = 5386 gal
5. 14 ft × 12 ft × 6 ft × 7.48 gal/$ft^3$ = 7540 gal
6. 9 ft × 9 ft × 6 ft = 486 $ft^3$
7. 12 ft × 8 ft × $x$ ft × 7.48 gal/$ft^3$ = 4850 gal, $x$ = 6.8 ft
8. 10 ft × 8 ft × 3.1 ft × 7.48 gal/$ft^3$ = 1855 gal
9. $$\frac{10 \text{ ft} \times 10 \text{ ft} \times 1.8 \text{ ft} \times 7.48 \text{ gal/ft}^3}{5 \text{ min}} = 269 \text{ gpm}$$
10. $$\frac{12 \text{ ft} \times 12 \text{ ft} \times 1.3 \text{ ft} \times 7.48 \text{ gal/ft}^3}{3 \text{ min}} = 467 \text{ gpm}$$

11. $\dfrac{9\text{ ft} \times 7\text{ ft} \times 1.4\text{ ft} \times 7.48\text{ gal/ft}^3}{3\text{ min}} = 220\text{ gpm}$

12. $\dfrac{9\text{ ft} \times 8\text{ ft} \times 0.9\text{ ft} \times 7.48\text{ gal/ft}^3}{1\text{ min}} = 485\text{ gpm}$

13. 12 ft × 14 ft × –2.2 ft ×7.48 gal/ft$^3$ = –2765 gal

$$\frac{-2765\text{ gal}}{5\text{ min}} = -553\text{ gpm}$$

0 gpm = discharge + –553 gpm

533 gpm = discharge

14. $$\text{Accumulation} = \frac{12\text{ ft} \times 14\text{ ft} \times -1.9\text{ ft} \times 7.48\text{ gal/ft}^3}{4\text{ min}}$$

$$= -597\text{ gpm}$$

$$0\text{ gpm} = \text{discharge} + -597\text{ gpm}$$

$$597\text{ gpm} = \text{discharge}$$

15. 10 ft 9 in. = 10.75 ft

12 ft 2 in. = 12.17 ft

$$\text{Accumulation} = \frac{10.75\text{ ft} \times 12.12\text{ ft} \times -2\text{ ft} \times 7.48\text{ gal/ft}^3}{5.5\text{ min}} = -354\text{ gpm}$$

0 gpm = discharge + –354 gpm

354 gpm = discharge

16. 410 gpm = discharge + accumulation

$$\frac{11.8\text{ ft} \times 14\text{ ft} \times -0.083\text{ ft} \times 7.48\text{ gal/ft}^3}{7} = 14.5\text{ gpm}$$

410 gpm = discharge + 145 gpm

395.5 gpm = Discharge

17. 140 in. = 11.7 ft

148 in. = 12.3 ft

$$\text{Accumulation} = \frac{11.7\text{ ft} \times 12.3\text{ ft} \times -0.125\text{ ft} \times 7.48\text{ gal/ft}^3}{6\text{ min}} = -22.4\text{ gpm}$$

430 gpm = discharge + –22.4 gpm

452.4 gpm = discharge

18. $$\text{Total accumulation} = \frac{9.8\text{ ft} \times 14\text{ ft} \times -0.7\text{ ft} \times 7.48\text{ gal/ft}^3}{15\text{ min}} = -48\text{ gpm}$$

800 gpm = discharge + –48 gpm

848 gpm = discharge

848 gpm = 500 gpm + second pump discharge

348 gpm = second pump discharge

19. $\dfrac{60\text{ gpd}}{7.48\text{ gal/ft}^3} = 8\text{ ft}^3\text{/d}$

20. $\dfrac{282 \text{ gal/wk}}{7.48 \text{ gal/ft}^3 \times 7 \text{ d/wk}} = 5.4 \text{ ft}^3/\text{d}$

21. $\dfrac{4.9 \text{ ft}^3}{3.33 \text{ MGD}} = 1.5 \text{ ft}^3/\text{MG}$

22. $\dfrac{\dfrac{81 \text{ gal/d}}{7.48 \text{ gal/ft}^3}}{4.9 \text{ MGD}} = 2.2 \text{ ft}^3/\text{MG}$

23. $\dfrac{\dfrac{48 \text{ gal/d}}{7.48 \text{ gal/ft}^3}}{2.28 \text{ MGD}} = 2.8 \text{ ft}^3/\text{MG}$

24. $\dfrac{600 \text{ ft}^3}{2.9 \text{ ft}^3/\text{d}} = 207 \text{ d}$

25. $\dfrac{9 \text{ yd}^3 \times 27 \text{ ft}^3/\text{yd}^3}{1.6 \text{ ft}^3/\text{d}} = 152 \text{ d}$

26. $2.6 \text{ ft}^3/\text{MG} \times 2.9 \text{ MGD} = 7.5 \text{ ft}^3/\text{d}$

$\dfrac{292 \text{ ft}^3}{7.5 \text{ ft}^3/\text{d}} = 39 \text{ d}$

27. $\dfrac{x \text{ ft}^3}{3.5 \text{ ft}^3/\text{d}} = 120 \text{ d}$

$x = 420 \text{ ft}^3$

28. $4 \text{ ft} \times 1.6 \text{ ft} \times \text{fps} = \dfrac{1820 \text{ gpm}}{7.48 \text{ gal/ft}^3 \times 60 \text{ sec/min}}$

29. 26 ft/32 sec = 0.8 ft/sec

30. $3 \text{ ft} \times 1.2 \text{ ft} \times \text{fps} = 4.3 \text{ cfs} = 1.2 \text{ fps}$

31. 36 ft/32 sec = 1.2 fps

32. $2.8 \text{ ft} \times 1.3 \text{ ft} \times x \text{ fps} = \dfrac{1140 \text{ gpm}}{7.48 \text{ gal/ft}^3 \times 60 \text{ sec/min}}$

$x = 0.7 \text{ fps}$

33. $\dfrac{12 \text{ ft}^3/\text{d}}{8 \text{ MGD}} = 1.5 \text{ ft}^3/\text{MG}$

34. $\dfrac{260 \text{ gal/d}}{7.48 \text{ gal/ft}^3 \times 11.4 \text{ MGD}} = 3 \text{ ft}^3/\text{MG}$

35. $3.1 \text{ ft}^3/\text{MG} \times 3.8 \text{ MGD} = 11.8 \text{ ft}^3/\text{d}$

$11.8 \text{ ft}^3/\text{d} \times 30 \text{ d/month} = 354 \text{ ft}^3/\text{month}$

$\dfrac{354 \text{ ft}^3/\text{month}}{27 \text{ ft}^3/\text{yd}^3} = 13.1 \text{ yd}^3/\text{month}$

36. $2.2 \text{ ft}^3/\text{MG} \times 4.23 \text{ MGD} \times 90 \text{ d} = 838 \text{ ft}^3$ required

$\dfrac{838 \text{ ft}^3}{27 \text{ ft}^3/\text{yd}^3} = 31 \text{ yd}^3$

37. $2.6\text{ ft} \times 1.3\text{ ft} \times 1.1\text{ fps} = 3.7\text{ cfs}$

38. $3\text{ ft} \times 1.2\text{ ft} \times 1.4\text{ fps} \times 7.48\text{ gal/ft}^3 \times 60\text{ sec/min} \times 1440\text{ min/d} = 3{,}257{,}211\text{ gpd}$

39. $2.7\text{ ft} \times 0.83\text{ ft} \times 0.90\text{ fps} = 2\text{ cfs}$

40. $25.6782\text{ g} - 25.6662\text{ g} = 0.0120\text{ g}$

$0.0120\text{ g} \times 1000\text{ mg/L} = 12\text{ mg}/0.05\text{ L} = 240\text{ mg/L}$

41. $26.2410\text{ g} - 26.2345\text{ g} = 0.0065\text{ g}$

$0.0065\text{ g} \times 1000\text{ mg} = 6.5\text{ mg}$

$$\frac{6.5\text{ mg}}{0.026\text{ L}} = 250\text{ mg/L}$$

42. $8.42\text{ mg/L} - 4.28\text{ mg/L} = 4.14\text{ mg/L}$

$$\frac{6\text{ mL}}{300\text{ mL}} = 0.02$$

$$\frac{4.14\text{ mg/L}}{0.02} = 207\text{ mg/L}$$

43. $\text{BOD} = (7.96\text{ mg/L} - 4.26\text{ mg/L}) \times (300\text{ mL}/5\text{ mL}) = 222\text{ mg/L}$

44. $14.6\text{ mg/L} \times 3.13\text{ MGD} \times 8.34\text{ lb/gal} = 381\text{ lb/d}$

45. $310\text{ mg/L} \times 6.15\text{ MGD} \times 8.34\text{ lb/gal} = 15{,}900\text{ lb/d}$

46. $188\text{ mg/L} \times 4.85\text{ MGD} \times 8.34\text{ lb/gal} = 7604\text{ lb/d}$

47. $$\frac{270\text{ ft}^3}{2.6\text{ ft}^3/\text{MG} \times 2.95\text{ MGD}} = 35\text{ d}$$

48. $$\frac{210\text{ gal}}{7.48\text{ gal/ft}^3 \times 7\text{ d}} = 4\text{ ft}^3/\text{d}$$

49. $$\frac{5.4\text{ ft}^3}{2.91\text{ MGD}} = 1.85\text{ ft}^3/\text{MG}$$

50. $$\frac{12\text{ yd}^3 \times 27\text{ ft}^3/\text{yd}^3}{24\text{ ft}^3/\text{d}} = 135\text{ d}$$

51. $$\frac{36\text{ ft}}{31\text{ s}} = 1.2\text{ ft/s}$$

52. $26\text{ ft} \times 1.3\text{ ft} \times 0.8\text{ fps} = 2.7\text{ cfs}$

53. $$\frac{210\text{ gal}}{7.48\text{ gal/ft}^3 \times 8.8\text{ MGD}} = 3.2\text{ ft}^3/\text{MG}$$

54. $2.6\text{ ft} \times 1.3\text{ ft} \times 1.8\text{ ft/sec} \times 7.48\text{ gal/ft}^3 \times 60\text{ sec/min} = 2730\text{ gal}$

55. $2.3\text{ ft}^3/\text{MG} \times 3.61\text{ MGD} \times 30\text{ d} = 249\text{ ft}^3$

$$\frac{249\text{ ft}^3}{27\text{ ft}^3/\text{yd}^3} = 9.2\text{ yd}^3$$

56. $3\text{ ft} \times 0.83\text{ ft} \times 1\text{ fps} = 2.5\text{ cfs}$

57. $$\frac{160{,}000\text{ gal}}{75{,}417\text{ gph}} = 2.1\text{ hr}$$

58. $$\frac{90\text{ ft} \times 25\text{ ft} \times 10\text{ ft} \times 7.48\text{ gal/ft}^3}{135{,}416\text{ gph}} = 1.2\text{ hr}$$

59. $$\frac{0.785 \times 90\text{ ft} \times 90\text{ ft} \times 12\text{ ft} \times 7.48\text{ gal/ft}^3}{181{,}250\text{ gph}} = \frac{570{,}739}{181{,}250\text{ gph}} = 3.1\text{ hr}$$

60. 84 ft × 20 ft × 13.1 ft × 7.48 gal/ft$^3$ = 164,619 gal

$$\text{Detention time} = 164{,}619\text{ gal} \times \frac{1\text{ d}}{2{,}010{,}000\text{ gal}} \times 24\text{ hr/d} = 1.97\text{ hr}$$

61. 90 ft × 20 ft = 1800 ft$^2$

$$= \frac{1{,}450{,}000\text{ gpd}}{1800\text{ ft}^2} = 806\text{ gpd/ft}^2$$

62. 73.86 g – 22.20 g = 51.66 g (sample weight)

23.10 g – 22.20 g = 0.90 g (dry solids weight)

$$\frac{0.90\text{ g}}{51.66\text{ g}} \times 100\% = 1.7\%$$

63. 390 gal/min × 60 min/hr × 24 hr/d × 8.34 lb/gal × .8% = 37,470 lb/d

64. 140 mg/L – 50 mg/L = 90 mg/L

$$\%\text{ Removal} = \frac{90\text{ mg/L}}{140\text{ mg/L}} \times 100 = 64.2\%$$

65. $$\frac{1{,}420{,}000\text{ gpd}}{80\text{ ft}} = 17{,}750\text{ gpd/ft}$$

66. 80 ft × 20 ft × 12 ft × 7.48 gal/ft$^3$ = 143,616 gal

$$\text{Detention time} = 3\text{ tanks} \times 143{,}616\text{ gal} \times \frac{1}{5{,}000{,}000\text{ gal}} \times 24\text{ hr/d}$$

60 min/hr = 124 min

$$\text{Surface overflow rate} = \frac{5{,}000{,}000\text{ gpd}}{3 \times 80\text{ ft} \times 20\text{ ft}} = 1042\text{ gpd/ft}^2$$

$$\text{Weir overflow rate} = \frac{5{,}000{,}000\text{ gpd}}{3 \times 86\text{ ft}} = 19{,}380\text{ gpd/ft}$$

67. $$\frac{80\text{ ft} \times 35\text{ ft} \times 12\text{ ft} \times 7.48\text{ gal/ft}^3}{135{,}000\text{ gph}} = 1.9\text{ hr}$$

68. $$\frac{1{,}520{,}000\text{ gpd}}{112\text{ ft}} = 13{,}571\text{ gpd/ft}$$

69. $$\frac{2{,}980{,}000\text{ gpd}}{3.14 \times 70\text{ ft}} = 13{,}558\text{ gpd/ft}$$

70. $$\frac{2520\text{ gpm} \times 1440\text{ min/d}}{3.14 \times 90\text{ ft}} = 12{,}841\text{ gpd/ft}$$

71. $$\frac{1{,}880{,}000\text{ gpd}}{192\text{ ft}} = 9792\text{ gpd/ft}$$

72. $$\frac{2{,}910{,}000\text{ gpd}}{0.785 \times 70\text{ ft} \times 70\text{ ft}} = 756\text{ gpd/ft}^2$$

73. $$\frac{2{,}350{,}000\text{ gpd}}{80\text{ ft} \times 30\text{ ft}} = 979\text{ gpd/ft}^2$$

74. $\dfrac{2{,}620{,}000 \text{ gpd}}{80 \text{ ft} \times 30 \text{ ft}} = 1092 \text{ gpd/ft}^2$

75. $\dfrac{2610 \text{ gpd} \times 1440 \text{ min/d}}{0.785 \times 60 \text{ ft} \times 60 \text{ ft}} = 1330 \text{ gpd/ft}^2$

76. $\dfrac{3110 \text{ mg/L} \times 4.1 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.785 \times 70 \text{ ft} \times 70 \text{ ft}} = 27.6 \text{ lb/d/ft}^2$

77. $\dfrac{3220 \text{ mg/L} \times 4.4 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.785 \times 80 \text{ ft} \times 80 \text{ ft}} = 23.5 \text{ lb/d/ft}^2$

78. $\dfrac{2710 \text{ mg/L} \times 3.22 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.785 \times 70 \text{ ft} \times 70 \text{ ft}} = 18.9 \text{ lb/d/ft}^2$

79. $\dfrac{3310 \text{ mg/L} \times 2.98 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.785 \times 80 \text{ ft} \times 80 \text{ ft}} = 16.4 \text{ lb/d/ft}^2$

80. 125 mg/L × 5.55 MGD × 8.34 lb/gal = 5786 lb/d SS

81. 40 mg/L removed × 2.92 MGD × 8.34 lb/gal = 974 lb/d SS

82. 90 mg/L removed × 4.44 MGD × 8.34 lb/gal = 3333 lb/d BOD

83. 200 mg/L removed × 0.98 MGD × 8.34 lb/gal = 1635 lb/d SS

84. $\dfrac{135 \text{ mg/L removed}}{220 \text{ mg/L}} \times 100 = 61\%$ removal efficiency

85. $\dfrac{111 \text{ mg/L}}{188 \text{ mg/L}} \times 100 = 59\%$ removal efficiency

86. $\dfrac{220 \text{ mg/L removed}}{280 \text{ mg/L}} \times 100 = 79\%$ removal efficiency

87. $\dfrac{111 \text{ mg/L}}{300 \text{ mg/L}} \times 100 = 37\%$ removal efficiency

88. $\dfrac{0.785 \times 80 \text{ ft} \times 80 \text{ ft} \times 10 \text{ ft} \times 7.48 \text{ gal/ft}^3}{171{,}667 \text{ gph}} = 2.2 \text{ hr}$

89. $\dfrac{2{,}320{,}000 \text{ gpd}}{0.785 \times 60 \text{ ft} \times 60 \text{ ft}} = 821 \text{ gpd/ft}^2$

90. $\dfrac{3{,}728{,}000 \text{ gpd}}{215 \text{ ft}} = 17{,}340 \text{ gpd/ft}^2$

91. $\dfrac{2710 \text{ mg/L} \times 2.46 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.785 \times 60 \text{ ft} \times 60 \text{ ft}} = 19.7 \text{ lb/d/ft}^2$

92. $\dfrac{3{,}100{,}000 \text{ gpd}}{0.785 \times 70 \text{ ft} \times 70 \text{ ft}} = 860 \text{ gpd/ft}^2$

93. $\dfrac{2910 \text{ mg/L} \times 3.96 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.785 \times 80 \text{ ft} \times 80 \text{ ft}} = 19.1 \text{ lb/d/ft}^2$

94. 118 mg/L removed × 5.3 MGD × 8.34 lb/gal = 5216 lb/d removed

95. $\dfrac{90 \text{ ft} \times 40 \text{ ft} \times 14 \text{ ft} \times 7.48 \text{ gal/ft}^3}{212{,}500 \text{ gph}} = 1.8 \text{ hr}$

96. $\dfrac{1940\text{ gpm}\times 1440\text{ min/d}}{3.14\times 70\text{ ft}} = 12{,}698\text{ gpd/ft}$

97. 84 mg/L × 4.44 MGD × 8.34 lb/gal = 3110 lb/d BOD removed

98. 210 mg/L removed × 3.88 MGD × 8.34 lb/gal = 6795 lb/d removed

99. $\dfrac{191\text{ mg/L removed}}{260\text{ mg/L}}\times 100 = 73\%$

100. $\dfrac{2{,}220{,}000\text{ gpd}}{90\text{ ft}\times 40\text{ ft}} = 617\text{ gpd/ft}^2$

101. $\dfrac{780{,}000\text{ gpd}}{0.785\times 80\text{ ft}\times 80\text{ ft}} = 155\text{ gpd/ft}^2$

102. $\dfrac{2360\text{ gpm}\times 1440\text{ min/d}}{0.985\times 90\text{ ft}\times 90\text{ ft}} = 534\text{ gpd/ft}^2$

103. $\dfrac{1{,}500{,}000\text{ gpd}}{0.785\times 90\text{ ft}\times 90\text{ ft}} = 236\text{ gpd/ft}^2$

104. $\dfrac{0.785\times 96\text{ ft}\times 96\text{ ft}}{43{,}560\text{ ft}^2\text{/acre}} = 0.17\text{ acre}$

$\dfrac{2.1\text{ MGD}}{0.17\text{ acre}} = 12.4\text{ MGD/acre}$

105. $\dfrac{210\text{ mg/L}\times 1.4\text{ MGD}\times 8.34\text{ lb/gal}}{47.1\times 1000\text{ ft}^3} = 52\text{ lb BOD/1000 ft}^3$

106. $\dfrac{111\text{ mg/L}\times 3.40\text{ MGD}\times 8.34\text{ lb/gal}}{44.5\times 1000\text{ ft}^3} = 70.7\text{ lb BOD/d/1000 ft}^3$

107. $\dfrac{201\text{ mg/L}\times 0.9\text{ MGD}\times 8.34\text{ lb/gal}}{35.1\times 1000\text{ ft}^3} = 43\text{ lb BOD/d/1000 ft}^3$

108. $\dfrac{0.785\times 90\text{ ft}\times 90\text{ ft}\times 5\text{ ft}}{43{,}560\text{ ft}^3\text{/acre-ft}} = 0.73\text{ acre-ft}$

$\dfrac{120\text{ mg/L}\times 1.4\text{ MGD}\times 8.34\text{ lb/gal}}{0.73\text{ acre-ft}} = 1919\text{ lb BOD/d/acre-ft}$

109. 122 mg/L removed × 3.24 MGD × 8.34 lb/gal = 3297 lb/d SS removed

110. 176 mg/L removed × 1.82 MGD × 8.34 lb/gal = 2671 lb/d BOD removed

111. 182 mg/L BOD removed × 2.92 MGD × 8.34 lb/gal = 4432 lb/d BOD removed

112. 194 mg/L BOD removed × 5.4 MGD × 8.34 lb/gal = 8737 lb/d BOD removed

113. $\dfrac{101\text{ mg/L removed}}{149\text{ mg/L}}\times 100 = 68\%$ removal efficiency

114. $\dfrac{239\text{ mg/L removed}}{261\text{ mg/L}}\times 100 = 92\%$ removal efficiency

115. $\dfrac{179\text{ mg/L removed}}{201\text{ mg/L}}\times 100 = 89\%$ removal efficiency

116. $\dfrac{88 \text{ mg/L removed}}{111 \text{ mg/L}} \times 100 = 79\%$ removal efficiency

117. $\dfrac{3.5 \text{ MGD}}{3.4 \text{ MGD}} = 1$

118. $\dfrac{2.32 \text{ MGD}}{1.64 \text{ MGD}} = 1.4$

119. $\dfrac{3.86 \text{ MGD}}{2.71 \text{ MGD}} = 1.4$

120. $1.6 = \dfrac{x \text{ MGD}}{4.6 \text{ MGD}}$

$x = 7.4$ MGD

121. 0.310 MGD + 0.355 MGD = 0.655 MGD

Surface area = 0.785 × 90 ft × 90 ft = 6359 $ft^2$

$\dfrac{655{,}000 \text{ gpd}}{6359 \text{ ft}^2} = 103 \text{ gpd/ft}^2$

122. $\dfrac{4.55 \text{ MGD}}{2.8 \text{ MGD}} = 1.6$

123. 75 mg/L × 1.35 MGD × 8.34 lb/gal = 844.4 lb BOD/d

Surface area = 0.785 × 80 $ft^2$ × 80 $ft^2$ = 5024 $ft^2$

5024 $ft^2$ × 6 ft = 30,144 $ft^3$

$\dfrac{844.4 \text{ lb d} \times 100 \text{ lb BOD}}{30{,}144 \times 1000 \text{ ft}^3} = 28 \text{ lb BOD/1000 ft}^3$

124. 81 mg/L – 13 mg/L = 68 mg/L removed

68 mg/L × 4.1 MGD × 8.34 lb/gal = 2325 BOD/d

125. $\dfrac{630{,}000 \text{ gpd}}{0.785 \times 60 \text{ ft} \times 80 \text{ ft}} = 125 \text{ gpd/ft}^2$

126. $\dfrac{180 \text{ mg/L} \times 1.4 \text{ MGD} \times 8.34 \text{ lb/gal}}{38.2 \times 1000 \text{ ft}^3} = 55 \text{ lb BOD/d/1000 ft}^3$

127. 114 mg/L removed × 2.84 MGD × 8.34 lb/d = 2700 lb/d SS removed

128. $\dfrac{131 \text{ mg/L removed}}{200 \text{ mg/L}} \times 100 = 65.5\%$

129. 156 mg/L removed × 1.44 MGD × 8.34 lb/gal = 1873 lb/d removed

130. $\dfrac{2{,}880{,}000 \text{ gpd}}{0.785 \times 90 \text{ ft} \times 90 \text{ ft}} = 453 \text{ gpd/ft}^2$

131. $\dfrac{188 \text{ mg/L removed}}{210 \text{ mg/L}} \times 100 = 90\%$ removal efficiency

132. $\dfrac{141 \text{ mg/L} \times 2.33 \text{ MGD} \times 8.34 \text{ lb/gal}}{30.1 \times 1000 \text{ ft}^3} = 87 \text{ lb BOD/d/1000 ft}^3$

133. $\dfrac{0.785 \times 90 \text{ ft} \times 90 \text{ ft} \times 6 \text{ ft}}{43{,}560 \text{ ft}^3\text{/acre-ft}} = 0.9 \text{ acre-ft}$

$$\frac{144 \text{ mg/L} \times 1.26 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.9 \text{ acre-ft}} = 1681 \text{ BOD/d/acre-ft}$$

134. 178 mg/L removed × 4.22 MGD × 8.34 lb/gal = 6265 lb/d removed

135. $\frac{3.8 \text{ MGD}}{3.6 \text{ MGD}} = 1.1$

136. $\frac{0.785 \times 80 \text{ ft} \times 80 \text{ ft}}{43{,}560 \text{ ft}^2/\text{acre}} = 0.12 \text{ acre}$

$\frac{1.9 \text{ MGD}}{0.12 \text{ acre}} = 15.8 \text{ MGD/acre}$

137. $\frac{1{,}930{,}000 \text{ gpd}}{0.785 \times 90 \text{ ft} \times 90 \text{ ft}} = 304 \text{ gpd/ft}^2$

138. $\frac{166 \text{ mg/L} \times 0.81 \text{ MGD} \times 8.34 \text{ lb/gal}}{23.1 \times 1000 \text{ ft}^3} = 48 \text{ lb BOD/d/1000 ft}^3$

139. $\frac{2.35 \text{ MGD}}{1.67 \text{ MGD}} = 1.4$

140. $\frac{208 \text{ mg/L removed}}{243 \text{ mg/L}} \times 100 = 86\% \text{ removal efficiency}$

141. $\frac{2{,}980{,}000 \text{ gpd}}{720{,}000 \text{ ft}^2} = 4.1 \text{ gpd/ft}^2$

142. $\frac{4{,}725{,}000 \text{ gpd}}{880{,}000 \text{ ft}^2} = 5.4 \text{ gpd/ft}^2$

143. $\frac{1{,}550{,}000 \text{ gpd}}{440{,}000 \text{ ft}^2} = 3.5 \text{ gpd/ft}^2$

144. $\frac{x \text{ gpd}}{800{,}000 \text{ ft}^2} = 7 \text{ gpd/ft}^2$

$x$ = 5,600,000 gpd

145. 241 mg/L SS × 0.55 $K$ value = 133 mg/L particulate BOD

146. 222 mg/L total BOD = (241 mg/L × 0.5 $K$ value) + $x$ mg/L soluble BOD

$x$ = 102 mg/L soluble BOD

147. 240 mg/L total BOD = (150 mg/L × 0.5 $K$ value) + $x$ mg/L soluble BOD

$x$ = 165 mg/L soluble BOD

148. 288 mg/L total BOD = (268 mg/L × 0.6 $K$ value) + $x$ mg/L soluble BOD

$x$ = 127 mg/L soluble BOD

127 mg/L × 1.9 MGD × 8.34 lb/gal = 2012 lb/d soluble BOD

149. $\frac{160 \text{ mg/L} \times 4.35 \text{ MGD} \times 8.34 \text{ lb/gal}}{980 \times 1000 \text{ ft}^2} = 5.9 \text{ lb/d/1000 ft}^2$

150. $\frac{179 \text{ mg/L} \times 1.52 \text{ MGD} \times 8.34 \text{ lb/gal}}{640 \times 1000 \text{ ft}^2} = 3.5 \text{ lb/d/1000 ft}^2$

151. $\frac{128 \text{ mg/L} \times 2.82 \text{ MGD} \times 8.34 \text{ lb/gal}}{660 \times 1000 \text{ ft}^2} = 4.6 \text{ lb/d/1000 ft}^2$

152. 187 mg/L total BOD = (144 mg/L × 0.52) + $x$ mg/L soluble BOD

$x$ = 112 mg/L soluble BOD

$$\frac{112\text{ mg/L} \times 2.8\text{ MGD} \times 8.34\text{ lb/gal}}{765 \times 1000\text{ ft}^2} = 3.4\text{ lb/d/1000 ft}^2$$

153. $\dfrac{450{,}000\text{ gpd}}{190{,}000\text{ ft}^2} = 2.4\text{ gpd/ft}^2$

154. 190 mg/L – (0.6 × 210 mg/L) = 64 mg/L

155. $\dfrac{1.9\text{ MGD} \times 128\text{ mg/L} \times 8.34\text{ lb/gal}}{410{,}000\text{ ft}^2} \times 1000 = 4.9\text{ lb/d/1000 ft}^2$

156. 210 mg/L – (0.65 ×240 mg/L) = 54 mg/L

$$\frac{0.71\text{ MGD} \times 54\text{ mg/L} \times 8.34\text{ lb/gal}}{110{,}000\text{ ft}^2} \times 100 = 2.9\text{ lb/d/ft}^2$$

157. *Hydraulic loading:*

$$\frac{455{,}000\text{ gpd}}{206{,}000\text{ ft}^2} = 2.2\text{ gpd/ft}^2$$

*Unit organic loading:*

241 mg/L – (0.5 × 149 mg/L) = 166.5 mg/L

0.455 MGD × 166.5 mg/L × 8.34 lb/gal = 632 lb/d

$$\frac{632\text{ lb/d}}{206{,}000\text{ ft}^2} \times 1000 = 3.1\text{ lb/d/1000 ft}^2$$

*First-stage organic loading:*

$$\frac{632\text{ lb/d}}{0.785 \times 103{,}000\text{ ft}^3} \times 1000 = 8.2\text{ lb/d/1000 ft}^2$$

$$\frac{632\text{ lb/d}}{103{,}000\text{ ft}^2} \times 1000 = 6.1\text{ lb/d/1000 ft}^2$$

158. $\dfrac{2{,}960{,}000\text{ gpd}}{660{,}000\text{ ft}^2} = 4.5\text{ gpd/ft}^2$

159. 222 mg/L × 0.5 $K$ value = 111 mg/L

160. $\dfrac{151\text{ mg/L} \times 1.92\text{ MGD} \times 8.34\text{ lb/gal}}{720 \times 1000\text{ ft}^2} = 3.4\text{ lb/d/1000 ft}^2$

161. 210 mg/L total BOD = (205 mg/L × 0.6) + $x$ mg/L soluble BOD

$x$ = 87 mg/L soluble BOD

87 mg/L × 2.9 MGD × 8.34 lb/gal = 2104 lb/d

162. $\dfrac{4{,}475{,}000\text{ gpd}}{910{,}000\text{ ft}^2} = 4.9\text{ gpd/ft}^2$

163. $\dfrac{121\text{ mg/L} \times 2.415\text{ MGD} \times 8.34\text{ lb/gal}}{760 \times 1000\text{ ft}^2} = 3.2\text{ lb/d/1000 ft}^2$

164. 80 ft × 30 ft × 14 ft × 7.48 gal/ft$^3$ = 251,328 gal

165. 80 ft × 30 ft × 12 ft × 7.48 gal/ft$^3$ = 215,424 gal

166. 0.785 × 80 ft × 80 ft × 12 ft × 7.48 gal/ft$^3$ = 450,954 gal

167. 0.785 × 70 ft × 70 ft × 10 ft × 7.48 gal/ft$^3$ = 287,718 gal

168. 240 mg/L × 0.88 MGD × 8.34 lb/gal = 1761 lb/d BOD

169. 160 mg/L × 4.29 MGD × 8.34 lb/gal = 5725 lb/d COD

170. 165 mg/L × 3.24 MGD × 8.34 lb/gal = 4459 lb/d BOD

171. 150 mg/L × 4.88 MGD × 8.34 lb/gal = 6105 lb/d BOD

172. 2110 mg/L × 0.46 MG × 8.34 lb/gal = 8095 lb MLSS

173. 2420 mg/L × 0.54 MG × 8.34 lb/gal = 10,899 lb MLVSS

174. 2410 mg/L × 0.38 MG × 8.34 lb/gal = 7638 lb MLVSS

175. 2740 mg/L × 0.39 MG × 8.34 lb/gal = 8912 lb MLVSS

176. 2470 mg/L × 0.66 MG × 8.34 lb/gal × 0.73 = 9925 lb MLVSS

177. $$\frac{198 \text{ mg/L} \times 2.72 \text{ MGD} \times 8.34 \text{ lb/gal}}{2610 \text{ mg/L} \times 0.48 \text{ MG} \times 8.34} = 0.43$$

178. $$\frac{148 \text{ mg/L} \times 3.35 \text{ MGD} \times 8.34 \text{ lb/gal}}{2510 \text{ mg/L} \times 0.49 \text{ MG} \times 8.34} = 0.40$$

179. $$\frac{180 \text{ mg/L} \times 0.32 \text{ MGD} \times 8.34 \text{ lb/gal}}{2540 \text{ mg/L} \times 0.195 \text{ MG} \times 8.34 \text{ lb/gal}} = 0.12$$

180. $$\frac{181 \text{ mg/L} \times 3.3 \text{ MGD} \times 8.34 \text{ lb/gal}}{x \text{ lb MLVSS}} = 0.7$$

$x$ = 7116 lb MLVSS

181. $$\frac{141 \text{ mg/L} \times 2.51 \text{ MGD} \times 8.34 \text{ lb/gal}}{x \text{ lb MLVSS}} = 0.4$$

$x$ = 7379 lb MLVSS

182. $$\frac{16{,}100 \text{ lb MLVSS}}{2630 \text{ lb/d}} = 6.1 \text{ d}$$

183. $$\frac{2720 \text{ mg/L} \times 0.48 \text{ MG} \times 8.34 \text{ lb/gal}}{110 \text{ mg/L} \times 2.9 \text{ MGD} \times 8.34 \text{ lb/gal}} = 4.1 \text{ d}$$

184. $$\frac{2510 \text{ mg/L} \times 0.57 \text{ MGD} \times 8.34 \text{ lb/gal}}{111 \text{ mg/L} \times 2.88 \text{ MGD} \times 8.34 \text{ lb/gal}} = 4.5 \text{ d}$$

185. $$\frac{2960 \text{ mg/L} \times 0.58 \text{ MGD} \times 8.34 \text{ lb/gal}}{110 \text{ mg/L} \times 1.98 \text{ MGD} \times 8.34 \text{ lb/gal}} = 7.9 \text{ d}$$

186. $$\frac{3810 \text{ mg/L} \times 0.211 \text{ MGD} \times 8.34 \text{ lb/gal}}{205 \text{ mg/L} \times 0.27 \text{ MGD} \times 8.34 \text{ lb/gal}} = 14.6 \text{ d}$$

187. $$\frac{29{,}1000 \text{ lb}}{2920 \text{ lb/d} + 400 \text{ lb/d}} = 8.8 \text{ d}$$

188. $$\frac{(2710 \text{ mg/L} \times 1.5 \text{ MG} \times 8.34 \text{ lb/gal}) + (1940 \text{ mg/L} \times 0.106 \text{ MG} \times 8.34 \text{ lb/gal})}{(5870 \text{ mg/L} \times 0.072 \text{ MGD} \times 8.34 \text{ lb/gal}) + (25 \text{ mg/L} \times 3.3 \text{ MGD} \times 8.34 \text{ lb/gal})}$$

$$\frac{33{,}902 \text{ lb} + 1715 \text{ lb}}{3225 \text{ lb/d} + 688 \text{ lb/d}} = 9.1 \text{ d}$$

189. $$\frac{2222 \text{ mg/L} \times 0.612 \text{ MG} \times 8.34 \text{ lb/gal}}{1610 \text{ lb/d} + 240 \text{ lb/d}} = 6.1 \text{ d}$$

190. $$\frac{2910\text{ mg/L} \times 0.475\text{ MG} \times 8.34\text{ lb/gal}}{(6210\text{ mg/L} \times 0.027\text{ MGD} \times 8.34\text{ lb/gal}) + (16\text{ mg/L} + 1.4\text{ MGD} \times 8.34\text{ lb/gal})}$$

$$\frac{11{,}528}{1398\text{ lb/d} + 187\text{ lb/d}} = 7.3\text{ d}$$

191. $$\frac{220\text{ mL/L}}{1000\text{ mL/L} - 220\text{ mL/L}} = 0.28$$

192. $$\frac{2480\text{ mg/L} \times (3.6\text{ MGD} + x\text{ MGD}) \times 8.34\text{ lb/gal} = 7840\text{ mg/L} \times x\text{ MGD}}{8.34\text{ lb/gal} + (7840\text{ mg/L} \times 0.061\text{ MGD} \times 8.34\text{ lb/gal})}$$

2480 mg/L × 3.6 MGD + $x$ MGD = (7840 mg/L × $x$ MGD) + (7840 mg/L × 0.061 mg/L)

8928 + 2480$x$ = 7840$x$ + 478

8450 MGD = 5360$x$

1.58 MGD = $x$

193. $$\frac{280\text{ mL/L}}{1000\text{ mL/L} - 280\text{ mL/L}} = 0.38$$

194. (7520 mg/L × $x$ MGD RAS) × 8.34 = 2200 mg/L × (6.4 MGD + $x$ MGD RAS) × 8.34

7520 × $x$ MGD = 2200 × (6.4 + $x$ MGD)

7520 $x$ = 14,080 + 2200$x$

5320$x$ = 14,080

$x$ = 2.65 MGD

195. $$\frac{3400\text{ lb/d BOD}}{x\text{ lb/d MLSS} \times (69/100)} = 0.5$$

$x$ = 9565 lb MLSS desired

196. 2710 mg/L × 0.79 MG × 8.34 lb/gal = 17,855 lb MLSS

17,855 lb MLSS – 14,900 lb MLSS = 2955 lb MLSS to be wasted

197. $$\frac{110\text{ mg/L} \times 3.10\text{ MGD} \times 8.34\text{ lb/gal}}{x\text{ lb MLSS} \times (68/100)} = 0.4$$

$x$ = 10,456 lb MLSS desired

2200 mg/L × 1.1 MG × 8.34 lb/gal = 20,183 lb MLSS actual

20,183 lb MLSS actual – 10,456 lb MLSS desired = 9727 lb MLSS to be wasted

198. $$\frac{x\text{ lb MLSS}}{3220\text{ lb/d}} = 5.6\text{ d desired sludge age}$$

$x$ = 18,032 lb MLSS desired

2900 mg/L × .910 MG × 8.34 lb/gal = 22,009 lb MLSS actual

22,009 lb MLSS actual – 18,032 lb MLSS desired = 3977 lb MLSS to be wasted

199. $$\frac{32{,}400\text{ lb MLSS}}{x\text{ lb/d WAS} + (23\text{ mg/L} \times 3.22\text{ MGD} \times 8.34\text{ lb/gal})} = 9\text{ d}$$

$$\text{WAS pumping rate} = \frac{32{,}400\text{ lb}}{x\text{ lb/d} + 618\text{ lb/d}} = 9\text{ d}$$

$$\frac{32{,}400}{9} = x\text{ lb/d} + 618\text{ lb/d}$$

$3600 \text{ lb/d} = x \text{ lb/d} + 618 \text{ lb/d}$

$2982 \text{ lb/d} = x$

200. $6640 \text{ mg/L} \times x \text{ MGD} \times 8.34 \text{ lb/gal} = 5580 \text{ lb/d dry solids}$

$x = 0.10 \text{ MGD}$

201. $6200 \text{ mg/L} \times x \text{ MGD} \times 8.34 \text{ lb/gal} = 8710 \text{ lb/d dry solids}$

$x = 0.17 \text{ MGD}$

202. $$\frac{2725 \text{ mg/L} \times 1.8 \text{ MG} \times 8.34 \text{ lb/gal}}{(7420 \text{ mg/L} \times x \text{ MGD} \times 8.34 \text{ lb/gal}) + (18 \text{ mg/L} \times 4.3 \text{ MGD} \times 8.34 \text{ lb/gal})} = 9 \text{ d}$$

$$\frac{40{,}908 \text{ lb MLSS}}{(7420 \text{ mg/L} \times x \text{ MGD} \times 8.34 \text{ lb/gal}) + 646 \text{ lb/d}} = 9 \text{ d}$$

$$\frac{40{,}908}{9} = (7420 \times x \times 8.34) + 646$$

$4545 = (7420 \times x \times 8.34) + 646$

$3899 = (7420 \times x \times 8.34)$

$x = 0.063 \text{ MGD}$

203. $$\frac{2610 \text{ mg/L} \times 1.7 \text{ MG} \times 8.34 \text{ lb/gal}}{(6140 \text{ mg/L} \times x \text{ MGD} \times 8.34 \text{ lb/gal}) + (14 \text{ mg/L} \times 3.8 \text{ MGD} \times 8.34 \text{ lb/gal})} = 8.5 \text{ d}$$

$$\frac{37{,}005 \text{ lb MLSS}}{(6140 \text{ mg/L} \times x \text{ MGD} \times 8.34 \text{ lb/gal}) + 444 \text{ lb/d}} = 8.5 \text{ d}$$

$$\frac{37{,}005}{8.5} = (6140 \times x \times 8.34) + 444$$

$4354 = (6140 \times x \times 8.34) + (444)$

$3910 = (6140 \times x \times 8.34)$

$x = 0.076 \text{ MGD}$

204. $$\frac{166{,}000 \text{ gal}}{7917 \text{ gph}} = 21 \text{ hr}$$

205. $$\frac{370{,}000 \text{ gal}}{9583 \text{ gph}} = 39 \text{ hr}$$

206. $$\frac{420{,}000 \text{ gal}}{12{,}708 \text{ gph}} = 33 \text{ hr}$$

207. $$\frac{210{,}000 \text{ gal}}{12{,}917 \text{ gph}} = 16 \text{ hr}$$

208. $80 \text{ ft} \times 4 \text{ ft} \times 15 \text{ ft} \times 7.48 \text{ gal/ft}^3 = 359{,}040 \text{ gal}$

209. $220 \text{ mg/L} \times 1.72 \text{ MGD} \times 8.34 \text{ lb/gal} = 3156 \text{ lb/d}$

210. $$\frac{222 \text{ mg/L} \times 0.399 \text{ MGD} \times 8.34 \text{ lb/gal}}{3340 \times 0.22 \text{ MG} \times 8.34 \text{ lb/gal} \times (68/100)} = 0.18$$

211. $0.785 \times 90 \text{ ft} \times 90 \text{ ft} \times 12 \text{ ft} \times 7.48 \text{ gal/ft}^3 = 570{,}739 \text{ gal}$

212. $160 \text{ mg/L} \times 3.92 \text{ MGD} \times 8.34 \text{ lb/gal} = 5231 \text{ lb/d}$

213. $$\frac{2700 \text{ mg/L} \times 0.53 \text{ MG} \times 8.34 \text{ lb/gal}}{190 \text{ mg/L} \times 1.8 \text{ MGD} \times 8.34 \text{ lb/d}} = 4.2 \text{ d}$$

214. $\dfrac{440 \text{ mL}}{2100 \text{ mL} - 440 \text{ mL}} = \dfrac{440 \text{ mL}}{1660 \text{ mL}} = 0.265$

$0.265 \times 6.1$ MGD = 1.62 MGD

$$\frac{1.62 \text{ MG}}{1} \times \frac{1 \text{ d}}{1440 \text{ min}} \times \frac{1{,}000{,}000 \text{ gal}}{1 \text{ million gal}} = 1125 \text{ gpm}$$

215. MLSS:

2100 mg/L – 2050 mg/L = 50 mg/L (in excess)

50 mg/L × 0.45 MG × 8.34 lb/gal = 188 lb

188 lb/d = 4920 mg/L × additional WAS (MGD) × 8.34 lb/gal

$$\frac{188}{4920 \times 8.34} = 0.0046 \text{ MGD (additional WAS)}$$

New WAS = 0.120 MGD + 0.0046 MGD = 0.125 MGD

216. –80. We need an extra 80 mg/L MLSS in aeration

80 mg/L × 0.44 MG × 8.34 lb/gal = 294 lb (needed)

294 lb/d = 4870 mg/L × excess WAS (MGD) × 8.34 lb/gal

$$\frac{294}{4870 \times 8.34} = 0.007 \text{ MGD (excess WAS)}$$

$$\text{WAS} = \frac{87.3 \text{ gpm} \times 1440 \text{ min/d}}{1{,}000{,}000 \text{ gal}} = 0.126 \text{ MGD}$$

New WAS = 0.126 MGD – 0.007 MGD = 0.119 MGD

$$\frac{0.119 \text{ MGD} \times 1{,}000{,}000 \text{ gal}}{1440 \text{ min}} = 83 \text{ gpm}$$

217. $\dfrac{2210 \text{ mg/L} \times 0.66 \text{ MG} \times 8.34 \text{ lb/gal}}{131 \text{ mg/L} \times 3.25 \text{ MGD} \times 8.34 \text{ lb/gal}}$

$$\text{Sludge age} = \frac{1459 \text{ lb}}{426 \text{ lb/d}} = 3.42 \text{ d}$$

218. $\dfrac{146 \text{ mg/L} \times 2.88 \text{ MGD} \times 8.34 \text{ lb/gal}}{x \text{ lb MLVSS}} = 0.6$

$x$ = 5845 lb MLVSS

219. $\dfrac{310{,}000 \text{ gal}}{17{,}083 \text{ gph}} = 18 \text{ hr}$

220. $\dfrac{161 \text{ mg/L} \times 2.41 \text{ MGD} \times 8.34 \text{ lb/gal}}{x \text{ lb MLVSS}} = 0.8$

$x$ = 4045 lb MLVSS

221. $\dfrac{2910 \text{ mg/L} \times 0.46 \text{ MGD} \times 8.34 \text{ lb/gal}}{170 \text{ mg/L} \times 1.4 \text{ MG} \times 8.34 \text{ lb/gal}} = 5.8 \text{ d}$

222. $\dfrac{620{,}000 \text{ gal}}{15{,}000 \text{ gph}} = 41.3 \text{ lb}$

223. $\dfrac{3980 \text{ mg/L} \times 0.26 \text{ MGD} \times 8.34 \text{ lb/gal}}{200 \text{ mg/L} \times 0.4 \text{ MGD} \times 8.34 \text{ lb/gal}} = 13.0 \text{ d}$

224. $2710 \text{ mg/L} \times 0.44 \text{ MG} \times 8.34 \text{ lb/gal} = 9945 \text{ lb suspended solids}$

225. $$\frac{146 \text{ mg/L} \times 2.88 \text{ MGD} \times 8.34 \text{ lb/gal}}{x \text{ lb MLVSS}} = 0.4$$

$x = 8767 \text{ lb MLVSS}$

226. $2510 \text{ mg/L} \times 0.59 \text{ MG} \times 8.34 \text{ lb/gal} = 12{,}351 \text{ lb MLVSS}$

227. $$\frac{2740 \text{ mg/L} \times 0.710 \text{ MGD} \times 8.34 \text{ lb/d}}{184 \text{ mg/L} \times 1.86 \text{ MGD} \times 8.34 \text{ lb/gal}} = 5.7 \text{ d}$$

228. $$\frac{(2680 \text{ mg/L} \times 1.41 \text{ MG} \times 8.34 \text{ lb/gal}) + (1910 \text{ mg/L} \times 0.118 \text{ MG} \times 8.34 \text{ lb/gal})}{(5870 \text{ mg/L} \times 0.076 \text{ MGD} \times 8.34 \text{ lb/gal}) + (20 \text{ mg/L} \times 3.1 \text{ MGD} \times 8.34 \text{ lb/gal})} =$$

$$\frac{31{,}515 \text{ MLSS} + 1854 \text{ lb MLSS}}{3721 \text{ lb/d SS} + 517 \text{ lb/d SS}} = 7.9 \text{ d}$$

229. $$\frac{231 \text{ mL/L}}{769 \text{ mL/L}} = 0.30$$

230. $$\frac{3720 \text{ lb/d}}{x \text{ lb MLSS} \times (70/100)} = 0.5$$

$x = 10{,}629 \text{ lb MLSS}$

231. $$\frac{x \text{ lb MLSS}}{3740 \text{ lb/d SS}} = 5 \text{ d}$$

$x = 18{,}700 \text{ lb MLSS}$

$2810 \text{ mg/L} \times 0.78 \text{ MG} \times 8.34 \text{ lb/gal} = 18{,}280 \text{ lb MLSS}$

No MLSS should be wasted

232. $6410 \text{ mg/L} \times x \text{ MGD} \times 8.34 \text{ lb/gal} = 4110 \text{ lb/d}$

$x = 0.077 \text{ MGD}$

233. $250 \text{ mg/L} \times 0.41 \text{ MGD} \times 8.34 \text{ lb/gal} = 855 \text{ lb/d}$

234. $161 \text{ mg/L} \times 0.225 \text{ MGD} \times 8.34 \text{ lb/gal} = 302 \text{ lb/d}$

235. $223 \text{ mg/L} \times 0.259 \text{ MGD} \times 8.34 \text{ lb/gal} = 482 \text{ lb/d}$

236. $200 \text{ mg/L} \times 0.19 \text{ MGD} \times 8.34 \text{ lb/gal} = 317 \text{ lb/d}$

237. $$\frac{192 \text{ mg/L} \times 0.219 \text{ MGD} \times 8.34 \text{ lb/gal}}{7.8 \text{ acre}} = 46 \text{ lb/d/acre}$$

238. $$\frac{145 \text{ mg/L} \times 0.167 \text{ MGD} \times 8.34 \text{ lb/gal}}{7.1 \text{ acre}} = 28.4 \text{ lb/d/acre}$$

239. $$\frac{128 \text{ mg/L} \times 0.072 \text{ gpd} \times 8.34 \text{ lb/gal}}{2.2 \text{ acre}} = 35 \text{ lb/d/acre}$$

240. $$\frac{189 \text{ mg/L} \times x \text{ MGD} \times 8.34 \text{ lb/gal}}{15 \text{ acre}} = 22 \text{ lb}$$

$x = 0.21 \text{ MGD}$

241. $$\frac{169 \text{ mg/L removed}}{210 \text{ mg/L total}} \times 100 = 80\% \text{ BOD removed}$$

242. $$\frac{140 \text{ mg/L}}{267 \text{ mg/L}} \times 100 = 52\%$$

243. $\dfrac{246 \text{ mg/L}}{290 \text{ mg/L}} \times 100 = 85\% \text{ BOD removed}$

244. $\dfrac{84 \text{ mg/L removed}}{142 \text{ mg/L total}} \times 100 = 59\% \text{ BOD removed}$

245. $\dfrac{3.6 \text{ acre-ft/d}}{22 \text{ acre}} = 0.164 \text{ ft/d}$

$0.164 \text{ ft/d} \times 12 \text{ in./ft} = 2 \text{ in./d}$

246. $\dfrac{6 \text{ acre-ft/d}}{16 \text{ acre}} = 0.38 \text{ ft/d}$

$0.38 \text{ ft/d} \times 12 \text{ in./ft} = 4.6 \text{ in./d}$

247. $\dfrac{2{,}410{,}000 \text{ gpd}}{7.48 \text{ gal/ft}^3 \times 43{,}560 \text{ ft}^3\text{/acre-ft}} 7.4 \text{ acre-ft}$

$\dfrac{7.4 \text{ ac-ft/d}}{17 \text{ acre}} = 0.44 \text{ ft/d}$

$0.44 \text{ ft/d} \times 12 \text{ in./ft} = 5.3 \text{ in./d}$

248. $16 \text{ acre} \times 43{,}560 \text{ ft}^2\text{/acre} = 696{,}960 \text{ ft}^2$

$\dfrac{1{,}880{,}000 \text{ gpd}}{696{,}960 \text{ ft}^2} = 2.70 \text{ gpd/ft}^2$

$\dfrac{2.70 \text{ gpd/ft}^2 \times 1.6 \text{ in./d}}{\text{gpd/ft}^2} = 4.3 \text{ in./d}$

249. $\dfrac{1340 \text{ people}}{5 \text{ acre}} = 268 \text{ people/acre}$

250. $\dfrac{5580 \text{ people}}{19 \text{ acre}} = 294 \text{ people/acre}$

251. $\dfrac{1640 \text{ mg/L} \times 0.8 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.2 \text{ lb BOD/d/person}} = 54{,}710 \text{ people}$

252. $\dfrac{2260 \text{ mg/L} \times 0.257 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.2 \text{ lb BOD/d/person}} = 24{,}220 \text{ people}$

253. $\dfrac{19 \text{ acre-ft}}{0.44 \text{ acre-ft/d}} = 43 \text{ d}$

254. $\dfrac{450 \text{ ft} \times 700 \text{ ft} \times 8 \text{ ft} \times 7.48 \text{ gal/ft}^3}{300{,}000 \text{ gpd}} = 63 \text{ d}$

255. $\dfrac{250 \text{ ft} \times 400 \text{ ft} \times 6 \text{ ft} \times 7.48 \text{ gal/ft}^3}{72{,}000 \text{ gpd}} = 62 \text{ d}$

256. $\dfrac{33 \text{ acre}}{0.48 \text{ acre-ft/d}} = 68 \text{ d}$

257. $720 \text{ ft} \times 460 \text{ ft} \times 6 \text{ ft} \times 7.48 \text{ gal/ft}^3 = 14{,}864{,}256 \text{ gal}$

$\dfrac{14{,}864{,}256 \text{ gal}}{310{,}000 \text{ gal/d}} = 48 \text{ d}$

258. 705 ft × 430 ft × 4.17 ft = 1,264,136 ft$^3$

0.50 acre-ft/d × 43,560 ft$^3$ = 21,780 ft$^3$/d

$$\frac{1{,}264{,}136\ \text{ft}^3}{21{,}780\ \text{ft}^3} = 58\ \text{d}$$

259. 0.16 MGD × 171 mg/L × 8.34 lb/gal = 228.2 lb/d

$$\frac{698\ \text{ft} \times 395\ \text{ft}}{43{,}560\ \text{ft}^2} = 6.33\ \text{acre}$$

$$\frac{228.2\ \text{lb/d}}{6.33\ \text{acre}} = 36.1\ \text{lb/d acre}$$

260. $$\frac{750\ \text{ft} \times 435\ \text{ft}}{43{,}560\ \text{ft}^2} = 7.49\ \text{acre}$$

$$\frac{0.79\ \text{acre-ft/d} \times 12\ \text{in./ft}}{7.49\ \text{acre}} = 1.27\ \text{in./d}$$

261. 192 mg/L × 0.37 MGD × 8.34 lb/d = 592 lb/d

262. $$\frac{240\ \text{mg/L} \times 0.285\ \text{MGD} \times 8.34\ \text{lb/gal}}{9.1\ \text{acre}} = 63\ \text{lb/d/acre}$$

263. $$\frac{176\ \text{mg/L BOD removed}}{220\ \text{mg/L BOD total}} \times 100 = 80\%\ \text{BOD removed}$$

264. $$\frac{3.8\ \text{acre-ft/d}}{22\ \text{acre}} = 0.17\ \text{ft/d}$$

0.17 ft/d × 12 in./d = 2 in./d

265. $$\frac{93\ \text{mg/L removed}}{166\ \text{mg/L total}} \times 100 = 56\%$$

266. 222 mg/L × 0.302 MGD × 8.34 lb/gal = 559 lb/d

267. $$\frac{135\ \text{mg/L} \times 0.080\ \text{MGD} \times 8.34\ \text{lb/gal}}{\dfrac{400\ \text{ft} \times 220\ \text{ft}}{43{,}560\ \text{ft}^2/\text{acre}}} = 45\ \text{lb/d/acre}$$

268. $$\frac{1{,}980{,}000\ \text{gpd}}{21\ \text{acre} \times 43{,}560\ \text{ft}^2/\text{acre}} = 2.2\ \text{gpd/ft}^2$$

$$\frac{2.2\ \text{gpd/ft}^2 \times 1.6\ \text{in./d}}{\text{gpd/ft}^2} = 3.5\ \text{in./d}$$

269. $$\frac{6200\ \text{people}}{22\ \text{acre}} = 282\ \text{people/acre}$$

270. $$\frac{18.4\ \text{acre-ft}}{0.52\ \text{acre-ft/d}} = 35\ \text{d}$$

271. $$\frac{2910\ \text{mg/L} \times 0.9\ \text{MGD} \times 8.34\ \text{lb/gal}}{0.4\ \text{lb BOD/d/person}} = 54{,}606\ \text{people}$$

272. $$\frac{440\ \text{ft} \times 730\ \text{ft} \times 6\ \text{ft} \times 7.48\ \text{gal/ft}^3}{450{,}000\ \text{gpd}} = 32\ \text{d}$$

273. 3.4 mg/L × 4.6 MGD × 8.34 lb/gal = 130 lb/d

274. 11 mg/L × 1.68 MGD × 8.34 lb/gal = 154 lb/d

275. 2200 mg/L × 0.200 MGD × 8.34 lb/gal = 3578 lb/d

276. $x$ mg/L × 5.12 MGD × 8.34 lb/gal = 320 lb/d

$x$ = 7.5 mg/L

277. 4.9 mg/L + 0.8 mg/L = 5.7 mg/L

278. 8.8 mg/L = $x$ mg/L + 0.9 mg/L

$x$ = 7.9 mg/L

279. 7.9 mg/L + 0.6 mg/L = 8.5 mg/L

280. 10.7 mg/L × 4.0 MGD × 8.34 lb/gal = 357 lb/d

281. $$\frac{11.1 \text{ mg/L} \times 2.88 \text{ MGD} \times 8.34 \text{ lb/gal}}{65/100} = 410 \text{ lb/d}$$

282. $$\frac{9.8 \text{ mg/L} \times 4.1 \text{ MGD} \times 8.34 \text{ lb/gal}}{60/100} = 559 \text{ lb/d}$$

283. $$\frac{19 \text{ mg/L} \times 1.724 \text{ MGD} \times 8.34 \text{ lb/gal}}{65/100} = 420 \text{ lb/d}$$

284. $$\frac{x \text{ mg/L} \times 5.65 \text{ MGD} \times 8.34 \text{ lb/gal}}{65/100} = 950 \text{ lb}$$

$x$ = 13 mg/L

285. $$\frac{0.75 \text{ lb}}{(16 \text{ gal} \times 8.34 \text{ lb/gal}) + 0.75 \text{ lb}} \times 100 = 0.56\%$$

286. $$\frac{x \text{ lb}}{(24 \text{ gal} \times 8.34 \text{ lb/gal}) + x \text{ lb}} \times 100 = 0.9$$

$$\frac{100\ x}{200 \text{ lb} + x \text{ lb}} = 0.9$$

$100x$ lb = 0.9 lb × (200 lb + $x$ lb)

$100x = 180 + 0.9x$

$99.1x = 180$

$x$ = 1.8 lb

287. 160 g = 0.35 lb

$$\frac{0.35 \text{ lb}}{(12 \text{ gal} \times 8.34 \text{ lb/gal}) + 0.3 \text{ lb}} \times 100 = 0.3\%$$

288. (10/100) × $x$ lb liquid polymer = (0.5/100) × 172/lb polymer solution

$x$ = 8.6 lb liquid polymer

289. (10/100) × $x$ gal liquid polymer × 10.4 lb/gal = (0.3/100) × 55 gal polymer solution × 8.34 lb/gal = 1.3 gal liquid polymer

290. (12/100) × $x$ gal × 10.3 lb/gal = (0.6/100) × 111 gal × 8.34 lb/gal

$x$ = 4.5 gal

291. $$\frac{[(10/100) \times 26 \text{ lb}] + [(0.5/100) \times 100 \text{ lb}]}{26 \text{ lb} + 110 \text{ lb}} \times 100 =$$

$$\frac{3.15 \text{ lb}}{136 \text{ lb}} \times 100 = 2.3\% \text{ strength}$$

292. $$\frac{\left[(12/100)\times 16\text{ gal}\times 10.2\text{ lb/gal}\right]+\left[(0.3/100)\times 30\text{ gal}\times 8.4\text{ lb/gal}\right]}{(6\text{ gal}\times 10.2\text{ lb/gal})+(30\text{ gal}\times 8.34\text{ lb/gal})}\times 100=$$

$$\frac{7.3\text{ lb}+0.8\text{ lb}}{61\text{ lb}+250\text{ lb}}\times 100=2.6\%\text{ strength}$$

293. $$\frac{\left[(10/100)\times 12\text{ gal}\times 10.2\text{ lb/gal}\right]+\left[(0.28/100)\times 42\text{ gal}\times 8.34\text{ lb/gal}\right]}{(12\text{ gal}\times 10.2\text{ lb/gal})+(42\text{ gal}\times 8.34\text{ lb/gal})}\times 100=$$

$$\frac{12.24\text{ lb}+0.98\text{ lb}}{122.4\text{ lb}+350.3\text{ lb}}\times 100=2.8\%\text{ strength}$$

294. 10 mg/L × 4.10 MGD × 8.34 lb/gal = 342 lb/d alum required

$$\frac{342\text{ lb/d}}{5.88\text{ lb alum/gal solution}}=58\text{ gpd solution}$$

295. 8 mg/L × 1.44 MGD × 8.34 lb/gal = 96 lb/gal alum required

$$\frac{96\text{ lb/d}}{6.15\text{ lb}}=15.6\text{ gpd solution}$$

296. 11 mg/L × 2.13 MGD × 8.34 lb/gal = 600,000 mg/L × $x$ MGD × 8.34 lb/gal
$x$ = 0.000039 MGD, or 39 gpd solution

297. 9 mg/L × 4.44 MGD × 8.34 lb/gal = 600,000 mg/L × $x$ MGD × 8.34 lb/gal
$x$ = 0.0000666 MGD, or 66.6 gpd

298. $$\frac{30\text{ gpm}}{80\text{ gpm}}\times 100=37.5\%$$

299. $$\frac{22\text{ gpm}}{80\text{ gpm}}\times 100=27.5\%$$

300. $$\frac{14\text{ gpm}}{70\text{ gpm}}\times 100=20\%$$

301. $$\frac{40\text{ gpm}}{110\text{ gpm}}\times 100=36\%$$

302. $$\frac{35\text{ gpd}\times 3785\text{ mL/gal}}{1440\text{ min/d}}=92\text{ mL/min}$$

303. $$\frac{45\text{ gal/d}\times 3785\text{ mL/gal}}{1440\text{ min/d}}=118\text{ mL/min}$$

304. 9 mg/L × 0.91 MGD × 8.34 lb/gal = 600,000 mg/L × $x$ MGD × 8.34 lb/gal
$x$ = 0.000136 MGD, or 13.6 gpd

$$\frac{13.6\text{ gal/d}\times 3785\text{ mL/gal}}{1440\text{ min/d}}=36\text{ mL/min}$$

305. 11 mg/L × 1.42 MGD × 8.34 lb/gal = 600,000 mg/L × $x$ MGD × 8.34 lb/gal
$x$ = 0.000026 MGD, or 26 gpd

$$\frac{26\text{ gal/d}\times 3785\text{ mL/gal}}{1440\text{ min/d}}=68\text{ mL/min}$$

306. $\dfrac{2.1 \text{ lb}}{30 \text{ min}} = 0.07 \text{ lb/min}$

0.07 lb/min × 1440 min/d = 101 lb/d

307. $\dfrac{1.5 \text{ lb}}{30 \text{ min}} = 0.05 \text{ lb/min}$

0.05 lb/min × 1440 min/d = 72 lb/d

308. 12 oz = 0.75 lb

2.10 lb container and chemical – .75 lb container = 1.35 lb chemical

$$\frac{1.35 \text{ lb chemical}}{30 \text{ min}} = 0.045 \text{ lb/min}$$

0.045 lb/min × 1440 min/d = 65 lb/d

309. 2.5 lb chemical and container – 0.5 lb container = 2.0 lb chemical

$$\frac{2.0 \text{ lb chemical}}{30 \text{ min}} = 0.067 \text{ lb/min}$$

0.067 lb/min × 1440 min/d = 96.5 lb/d

310. $\dfrac{770 \text{ mL}}{5 \text{ min}} = 154 \text{ mL/min}$

$$\frac{154 \text{ mL/min} \times 1 \text{ gal}}{3785 \text{ mL}} = 59 \text{ gpd solution}$$

14,000 mg/L × 0.000059 MGD × 8.34 lb/gal = 6.9 lb/d polymer

311. $\dfrac{900 \text{ mL}}{5 \text{ min}} = 180 \text{ mL/min}$

$$\frac{180 \text{ mL}}{\text{min}} \times \frac{1 \text{ L}}{1000 \text{ mL}} \times \frac{1 \text{ gal}}{3785 \text{ L}} \times 1440 \text{ min/d} = 66.0 \text{ gpd solution}$$

12,000 mg/L × 0.000066 MGD × 8.34 lb/gal = 6.6 lb/d

312. $\dfrac{610 \text{ mL}}{5 \text{ min}} = 122 \text{ mL/min}$

$$\frac{120 \text{ mL/min} \times 1 \text{ gal}}{3785 \text{ L}} \times 1440 \text{ min/d} = 46 \text{ gpd solution}$$

13,000 mg/L × 0.000046 MGD × 8.34 lb/gal × 1.2 specific gravity = 6.0 lb/d

313. $\dfrac{800 \text{ mL}}{5 \text{ min}} = 160 \text{ mL/min}$

$$\frac{160 \text{ mL}}{\text{min}} \times \frac{1 \text{ gal}}{3785 \text{ L}} \times \frac{1440 \text{ min}}{\text{d}} = 61 \text{ gpd solution}$$

5000 mg/L × 0.000061 MGD × 8.34 lb/gal × 1.15 specific gravity = 2.9 lb/d

314. $\dfrac{0.785 \times 4 \text{ ft} \times 4 \text{ ft} \times 1.5 \text{ ft} \times 7.48 \text{ gal/ft}^3}{3 \text{ min}} = 47 \text{ gpm}$

315. $\dfrac{0.785 \times 5 \text{ ft} \times 5 \text{ ft} \times 1.25 \text{ ft} \times 7.48 \text{ gal/ft}^3}{5 \text{ min}} = 37 \text{ gpm}$

316. $\dfrac{0.785 \times 15 \text{ ft} \times 15 \text{ ft} \times x \text{ ft} \times 7.48 \text{ gal/ft}^3}{4 \text{ min}} = 30$

$x$ = 0.8 ft

317. $$\frac{0.785 \times 5 \text{ ft} \times 5 \text{ ft} \times 1.6 \text{ ft} \times 7.48 \text{ gal/ft}^3}{3 \text{ min}} = 78 \text{ gpm}$$

318. $$\frac{537}{7 \text{ d}} = 77 \text{ lb/d average}$$

319. $$\frac{2300 \text{ lb}}{115 \text{ lb/d}} = 20 \text{ d}$$

320. $$\frac{1002 \text{ lb}}{66 \text{ lb/d}} = 15.2 \text{ d}$$

321. $0.785 \times 95 \text{ ft} \times 5 \text{ ft} \times 3.4 \text{ ft} \times 7.48 \text{ gal/ft}^3 = 499 \text{ gal}$

$$\frac{499 \text{ gal}}{97 \text{ gpd}} = 5.1 \text{ d}$$

322. $11 \text{ mg/L} \times 3.75 \text{ MGD} \times 8.34 \text{ lb/gal} = 344 \text{ lb/d}$

323. $$\frac{7.1 \text{ mg/L} \times 3.24 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.65} = 295 \text{ lb/d}$$

324. $$\frac{x \text{ lb}}{(32 \text{ gal} \times 8.34 \text{ lb/gal}) + x \text{ lb}} \times 100 = 0.2$$

$$\frac{100x}{267 \text{ lb} + x} = 0.2$$

$100x = 0.2 \times (267 \text{ lb} + x)$

$100x = 53.4 + 0.2x$

$100x - 0.2x = 53.4$

$99.8x = 53.4$

$x = 53.4 \text{ lb}$

325. $$\frac{1.9 \text{ lb}}{30 \text{ min}} = 0.063 \text{ lb/min}$$

$0.063 \text{ lb/min} \times 1440 \text{ min/d} = 90.7 \text{ lb/d}$

326. $12 \text{ mg/L} \times 2.75 \text{ MGD} \times 8.34 \text{ lb/gal} = 275 \text{ lb/d alum}$

$$\frac{275 \text{ lb/d}}{5.88 \text{ lb alum/gal solution}} = 47 \text{ gpd solution}$$

327. $x \text{ mg/L} \times 5.115 \text{ MGD} \times 8.34 \text{ lb/gal} = 379 \text{ lb}$, $x = 8.8 \text{ mg/L}$

328. 12 oz = 0.75 lb; 2 lb 6 oz = 2.38 lb

2.38 lb chemical and container – .75 lb container = 1.63 lb chemical

$$\frac{1.63 \text{ lb}}{30 \text{ min}} = 0.054 \text{ lb/min}$$

$0.054 \text{ lb/min} \times 1440 \text{ min/d} = 78 \text{ lb/d}$

329. $10 \text{ mg/L} \times 3.244 \text{ MGD} \times 8.34 \text{ lb/gal} = 600{,}000 \text{ mg/L} \times x \text{ MGD} \times 8.34 \text{ lb/gal}$

$x = 0.000054$ MGD, or 54 gpd

330. $$\frac{32 \text{ gpm}}{90 \text{ gpm}} \times 100 = 35.5\%$$

331. $7.8 \text{ mg/L} = x \text{ mg/L} + 0.5 \text{ mg/L}$

$7.3 \text{ mg/L} = x$

332. $(12/100) \times x$ gal $\times$ 9.6 lb/gal = $(0.4/100) \times 60$ gal $\times$ 8.34 lb/gal

$x$ = 1.7 gal

333. $\dfrac{660\text{ mL}}{5\text{ min}} = 132\text{ mL/min}$

$$132\text{ mL/min} \times \frac{1\text{ gal}}{3785\text{ L}} \times 1440\text{ min/d} = 50.2\text{ gpd}$$

12,000 mg/L $\times$ 0.0000502 MGD $\times$ 8.34 lb/gal = 5 lb/d polymer

334. $\dfrac{0.785 \times 6\text{ ft} \times x\text{ ft} \times 7.48\text{ gal/ft}^3}{5\text{ min}} = 30\text{ gpm}$

$x$ = 0.71 ft

335. $\dfrac{20\text{ gpm}}{90\text{ gpm}} \times 100 = 22\%$

336. 9.6 mg/L $\times$ 4.3 MGD $\times$ 8.34 lb/gal = 344 lb/d

337. $\dfrac{2100\text{ lb}}{90\text{ lb/d}} = 23.3\text{ d}$

338. $50\text{ gal/d} \times 3785\text{ mL/gal} \times \dfrac{1\text{ d}}{1440\text{ min}} = 131\text{ mL/min}$

339. $\dfrac{888\text{ mL}}{5\text{ min}} = 178\text{ mL/min}$

$$178\text{ mL/min} \times \frac{1\text{ gal}}{3785\text{ L}} \times 1440\text{ min/d} = 68\text{ gpd}$$

9000 mg/L $\times$ 0.000068 MGD $\times$ 8.34 lb/gal = 5.1 lb/d polymer

340. 9 mg/L $\times$ 3.22 MGD $\times$ 8.34 lb/gal = 600,000 mg/L $\times$ $x$ MGD $\times$ 8.34 lb/gal

$x$ = 0.0000483 MGD, or 48 gpd

$$48\text{ gal/gal} \times 3785\text{ mL/gal} \times \frac{1\text{ d}}{1440\text{ min}} = 126\text{ mL/min}$$

341. $\dfrac{0.785 \times 4\text{ ft} \times 4\text{ ft} \times 1.25\text{ ft} \times 7.48\text{ gal/ft}^3}{3\text{ min}} = 39\text{ gpm}$

342. $\dfrac{11.1\text{ mg/L} \times 3.115\text{ MGD} \times 8.34\text{ lb/gal}}{0.65} = 444\text{ lb/d hypochlorite}$

343. $\dfrac{\left[(12/100) \times 6\text{ gal} \times 11.2\text{ lb/gal}\right] + \left[(0.3/100) \times 22\text{ gal} \times 8.34\text{ lb/gal}\right]}{(6\text{ gal} \times 11.2\text{ lb/gal}) + (22\text{ gal} \times 8.34\text{ lb/gal})} \times 100 =$

$$\frac{8.1\text{ lb} + 0.55\text{ lb}}{67.2 + 183.5} \times 100 = 3.45\%\text{ strength}$$

344. 160 mg/L $\times$ 4.82 MGD $\times$ 8.34 lb/gal = 6432 lb/d solids

345. 184 mg/L removed $\times$ 3.9 MGD $\times$ 8.34 lb/gal = 5985 lb/d solids

346. 135 mg/L BOD removed $\times$ 2.1 MGD $\times$ 8.34 lb/gal = 2364 lb/d BOD removed

$$\frac{0.5\text{ lb/d SS}}{1\text{ lb/d BOD removed}} = \frac{x\text{ lb/d SS}}{2364\text{ lb/d BOD removed}}$$

$x$ = 0.5 $\times$ 2364 = 1182 lb/d dry solids

347. 157 mg/L BOD removed × 2.84 MGD × 8.34 lb/gal = 3496 lb/d BOD removed

Use the *Y* value:

$$\frac{0.66 \text{ lb/d SS}}{1 \text{ lb/d BOD removed}} = \frac{x \text{ lb/d SS}}{3496 \text{ lb/d BOD removed}}$$

$x = 0.66 \times 3496$

$x = 2307$ lb/d dry solids

348. $x = \dfrac{0.71 \text{ g}}{31 \text{ g}} \times 100$

$x = 2.3\%$

349. $4.1 = \dfrac{8520 \text{ lb/d solids}}{x \text{ lb/d sludge}} \times 100$

$x = 202{,}857$ lb/d sludge

350. $5.5 = \dfrac{x \text{ lb/d solids}}{9350 \text{ gal sludge} \times 8.34 \text{ lb/gal}} \times 100$

$x = 4289$ lb/d solids

351. $5.3 = \dfrac{1490 \text{ lb/d solids}}{x \text{ gpd sludge} \times 8.34 \text{ lb/gal}} \times 100$

$x = 3371$ gpd sludge

352. $4.4 = \dfrac{900 \text{ lb/d solids}}{x \text{ gpd sludge} \times 8.34 \text{ lb/gal}} \times 100$

$x = 2452$ gpd sludge

353. 20,100 lb/d × 0.41 = $x$ lb/d × 0.06

$$\frac{20{,}100 \times 0.04}{0.06} = x$$

$x = 13{,}400$ lb/d thickened sludge

354. 2910 gpd × 8.34 lb/gal × 0.051 = $x$ gpd × 8.64 lb/gal × 0.06

$$\frac{2910 \times 8.31 \times 0.051}{8.64 \times 0.06} = x$$

$x = 2381$ gpd thickened sludge

355. 12,400 lb/d × 0.034 = $x$ lb/d × 0.054

$$\frac{12{,}400 \times 0.034}{0.054} = x$$

$x = 7807$ thickened sludge

356. 6100 gpd × 8.34 lb/gal × 0.041 = $x$ gpd × 8.6 lb/gal × 0.064

$$\frac{6100 \times 8.34 \times 0.041}{8.6 \times 0.064} = x$$

$x = 3793$ gpd thickened sludge

357. $\dfrac{(70 \text{ gpm} + 82 \text{ gpm}) \times 1440 \text{ min/d}}{0.785 \times 28 \text{ ft} \times 28 \text{ ft}} =$

$$\frac{152 \text{ gpm} \times 1440 \text{ min/d}}{615 \text{ ft}^2} = 356 \text{ gpd/ft}^2$$

358. $$\frac{162 \text{ gpm} \times 1440 \text{ min/d}}{0.785 \times 28 \text{ ft} \times 28 \text{ ft}} = 379 \text{ gpd/ft}^2$$

359. $$\frac{122{,}000 \text{ gpd} \times 8.34 \text{ lb/gal} \times (4.1/100)}{0.785 \times 44 \text{ ft} \times 44 \text{ ft}} = 27 \text{ lb/d/ft}^2$$

360. $$\frac{60 \text{ gpm} \times 1440 \text{ min/d} \times 8.34 \text{ lb/gal} \times (3.8/100)}{0.785 \times 32 \text{ ft} \times 32 \text{ ft}} = 34 \text{ lb/d/ft}^2$$

361. $$\frac{0.785 \times 46 \text{ ft} \times 46 \text{ ft} \times 3.8 \text{ ft} \times 7.48 \text{ gal/ft}^3}{28 \text{ gpm} \times 1440 \text{ min/d}} = 1.2 \text{ d}$$

362. $$\frac{0.785 \times 40 \text{ ft} \times 40 \text{ ft} \times 4.3 \text{ ft} \times 7.48 \text{ gal/ft}^3}{31 \text{ gpm} \times 60 \text{ min/hr}} = 21.7$$

363. 4% = 40,000 mg/L

0.9% = 9000 mg/L

$$\frac{31{,}000 \text{ mg/L removed}}{40{,}000 \text{ mg/L}} \times 100 = 78\%$$

364. $$\frac{2.7\% \text{ removed}}{3.3\% \text{ entering}} \times 100 = 82\%$$

365. $$\frac{8.4}{3.3} = 2.5$$

366. $$\frac{8.0}{3.1} = 2.6$$

367. Solids in: 130 gpm × 1440 min/d × 8.34 lb/gal × (3.6/100) = 56,205 lb/d

Solids out: 50 gpm × 1440 min/d × 8.34 lb/gal × (8.1/100) = 48,639 lb/d

Solids out of thickener: 130 gpm – 50 gpm × 1440 min/d × 8.34 × (0.059/100) = 567 lb/d

Solids entering = 56,205 lb/d

Solids leaving = 48,639 lb d + 567 lb/d = 49,206 lb/d

Because more solids are entering than are leaving, the sludge blanket will increase.

368. (a) Solids in: 110 gpm × 1440 min/d × 8.34 lb/gal × (3.6/100) = 47,558 lb/d

Underflow solids out: 65 gpm × 1440 min/d × 8.34 lb/gal × (7.1/100) = 55,424 lb/d

Efffluent solids out: (110 gpm – 65 gpm) × 1440 min/d × 8.34 × (0.052/100) = 281 lb/d

Solids entering = 47,558 lb/d

Solids out = 55,424 lb/d + 281 lb/d = 55,705 lb/d

Because more solids are leaving than are entering, the blanket will decrease.

(b) The pound per day decrease is 55,705 lb/d – 47,558 lb/d = 8,147 lb/d.

369. $$\frac{9400 \text{ lb/d}}{24 \text{ hr/d}} = 392 \text{ lb/hr}$$

$$\text{Fill time (hr)} = \frac{0.785 \times 30 \text{ ft} \times 30 \text{ ft} \times 1.8 \text{ ft} \times 7.48 \text{ gal/ft}^3 \times 8.34 \times (6.6/100)}{392 \text{ lb/hr}} = 13.4 \text{ hr}$$

370. $$\frac{14{,}000 \text{ lb/d}}{24 \text{ hr/d}} = 583 \text{ lb/hr}$$

$$\text{Fill time (hr)} = \frac{0.785 \times 30\text{ ft} \times 30\text{ ft} \times 2.5\text{ ft} \times 7.48\text{ gal/ft}^3 \times 8.34 \times (8/100)}{583\text{ lb/hr}} = 15.1\text{ hr}$$

371. $\dfrac{2.6\text{ ft}}{6\text{ ft}} \times \dfrac{x\text{ lb/min}}{60\text{ lb/min}}$

$$\frac{2.6 \times 60}{6} = x$$

$x$ = 26 lb/min solids storage rate

60 lb/min = $x$ lb/min withdrawal + 28 lb/min storage

$x$ = 32 lb/min solids withdrawal

$x$ gpm × 8.34 lb/gal × (5.6/100) = 32 lb/min

$$x = \frac{32}{8.34 \times 0.056}$$

$x$ = 69 gpm sludge withdrawal

372. $\dfrac{3.3\text{ ft}}{7\text{ ft}} = \dfrac{x\text{ lb/min}}{61\text{ lb/min}}$

$$\frac{3.3 \times 61}{7} = x$$

29 lb/min = $x$ solids storage rate

61 lb/min = $x$ lb/min withdrawal + 29 lb/min storage

29 lb/min = $x$ solids withdrawal

$x$ gpm × 8.34 lb/gal × (5.6/100) = 29 lb/min

$$x = \frac{29}{8.34 \times 0.056}$$

$x$ = 63 gpm sludge withdrawal

373. $\dfrac{910\text{ gpm}}{0.785 \times 40\text{ ft} \times 40\text{ ft}} = 0.7\text{ gpm/ft}^2$

374. $\dfrac{660\text{ gpm}}{0.785 \times 30\text{ ft} \times 30\text{ ft}} = 0.9\text{ gpm/ft}^2$

375. $\dfrac{8420\text{ mg/L} \times 0.17\text{ MGD} \times 8.34\text{ lb/gal}}{0.785 \times 40\text{ ft} \times 40\text{ ft}} = 9.5\text{ lb/d/ft}^2$

$$\frac{9.5\text{ lb/d/ft}^2}{24\text{ hr/d}} = 0.40\text{ lb/hr/ft}^2$$

376. $\dfrac{120\text{ gpm} \times 60\text{ min/hr} \times 8.34\text{ lb/gal} \times (0.7/100)}{65\text{ ft} \times 20\text{ ft}} = 0.3\text{ lb/hr/ft}^2$

377. 9 cfm × 60 min/hr × 0.075 lb/hr = 41 lb/hr

378. 12 cfm × 60 min/hr × 0.075 lb/ft$^3$ = 54 lb/hr

379. 8600 mg/L = 0.86% solids

$$\text{Air-to-solids ratio} = \frac{8\text{ cfm} \times 0.075\text{ lb/ft}^3}{85\text{ gpm} \times 8.34\text{ lb/gal} \times (0.86/100)} = 0.10$$

380. 7800 mg/L = 0.78% solids

$$\text{Air-to-solids ratio} = \frac{5 \text{ cfm} \times 0.075 \text{ lb/ft}^3}{60 \text{ gpm} \times 8.34 \text{ lb/gal} \times (0.78/100)} = 0.10$$

381. $\dfrac{90 \text{ gpm}}{85 \text{ gpm}} \times 100 = 106\%$

382. $112 = \dfrac{x \text{ gpm}}{70 \text{ gpm}} \times 100$

$$\frac{112 \times 70}{100} = x$$

$x = 78$ gpm

383. $\dfrac{7460 \text{ mg/L solids removed}}{7700 \text{ mg/L in influent}} \times 100 = 97\%$

384. $\dfrac{4.8}{0.841} = 5.6$

385. 40 gpm × 60 min/hr = 2400 gph

386. $\dfrac{86{,}400 \text{ gpd}}{24 \text{ hr/d}} = 3600 \text{ gph}$

387. 70 gpm × 60 min/hr × (30 min/31 min) = 4065 gph

388. $\dfrac{78{,}000 \text{ gpd} \times 25 \text{ min}}{24 \text{ hr/d} \times 27 \text{ min}} = 2990 \text{ gph}$

389. 7600 mg/L = 0.76%

$$\frac{110{,}000 \text{ gpd}}{24 \text{ hr/d}} \times 8.34 \text{ lb/gal} \times (0.76/100) = 291 \text{ lb/hr}$$

390. $80 \text{ gpm} \times 60 \text{ min/hr} \times 8.34 \text{ lb/gal} \times (0.75/100) \times \dfrac{30 \text{ min}}{32 \text{ min}} = 281 \text{ lb/hr}$

391. $\dfrac{32 \text{ ft}^3 \times 7.48 \text{ gal/ft}^3 \times 8.34 \text{ lb/gal} \times (6.6/100)}{70 \text{ gpm} \times 8.34 \text{ lb/gal} \times (0.73/100)} = 31 \text{ min}$

392. $\dfrac{22 \text{ ft}^3 \times 7.48 \text{ gal/ft}^3 \times 8.34 \text{ lb/gal} \times (9/100)}{55 \text{ gpm} \times 8.34 \text{ lb/gal} \times (0.76/100)} = 35 \text{ min}$

393. $\dfrac{7200 \text{ mg/L}}{8000 \text{ mg/L}} \times 100 = 90\%$

394. $\dfrac{0.67}{0.92} = 73\%$

395. $\dfrac{\left[16 \text{ ft}^3 \times 62.4 \text{ lb/ft}^3 \times (4.4/100)\right] + \left[4.0 \text{ ft}^3 \times 62.4 \text{ lb/ft}^3 \times (8.0/100)\right]}{\left(16 \text{ ft}^3 \times 62.4 \text{ lb}\right) + \left(4.0 \text{ ft}^3 \times 62.4 \text{ lb/ft}^3\right)} \times 100 =$

$$\frac{43.9 \text{ lb} + 19.9 \text{ lb}}{998 \text{ lb} + 250 \text{ lb}} \times 100 = 5.1\%$$

396. $$\frac{\left[12\ \text{ft}^3 \times 62.4\ \text{lb/ft}^3 \times (3.8/100)\right] + \left[4\ \text{ft}^3 \times 62.4\ \text{lb/ft}^3 \times (8.0/100)\right]}{\left(12\ \text{ft}^3 \times 62.4\ \text{lb/ft}^3\right) + \left(4\ \text{ft}^3 \times 62.4\ \text{lb/ft}^3\right)} \times 100 =$$

$$\frac{28.4\ \text{lb} + 19.9\ \text{lb}}{748.8\ \text{lb} + 249.6\ \text{lb}} \times 100 = 4.8\%$$

397. 48,400 gal/d × 8.34 lb/gal × (0.8/100) = 3229 lb/d

398. 0.785 × 24 ft × 24 ft = 452 $ft^2$

$$\frac{170\ \text{gpm} \times 1440\ \text{min/d}}{452\ \text{ft}^2} = 542\ \text{gpd/ft}^2$$

399. 240 gpm × 1440 min/d × 8.34 lb/gal × (1.3/100) = 37,470 lb/d

(0.785 × 40 ft × 40 ft = 1256 $ft^2$

$$\frac{37,470\ \text{lb/d}}{1256\ \text{ft}^2} = 30\ \text{lb/d/ft}^2$$

400. $$\frac{690\ \text{gpm}}{0.785 \times 34\ \text{ft} \times 34\ \text{ft}} = 0.76\ \text{gpm/ft}^2$$

401. 130 gal/min × 60 min/hr × 8.34 lb/gal × (0.98/100) = 637.5 lb/hr

0.785 × 30 ft × 30 ft = 706.5 $ft^2$

$$\frac{637.5}{706.5} = 0.90\ \text{lb/hr/ft}^2$$

402. 181 mg/L removed × 3.5 MGD × 8.34 lb/gal = 5283 lb/d SS

403. $$\frac{0.66\ \text{g}}{32\ \text{g}} \times 100 = 2.1\%$$

404. 3750 gpd × 8.34 lb/gal × (3.9/100) = $x$ gpd × 8.34 lb/gal × (8/100)

$$\frac{3750 \times 8.34 \times 0.039}{8.34 \times 0.08} = x$$

$x$ = 1828 gpd flow

405. 9550 gal × 8.34 lb/gal × (4.9/100) = 3903 lb/d solids

406. 132 mg/L BOD removed × 2.96 MGD × 8.34 lb/gal = 3259 lb/d BOD removed

$$\frac{0.5\ \text{lb SS}}{1\ \text{lb BOD removed}} = \frac{x\ \text{lb/d SS}}{3259\ \text{lb/d BOD removed}}$$

0.5 × 3259 = $x$

$x$ = 1630 lb/d SS produced

407. $$\frac{0.785 \times 42\ \text{ft} \times 42\ \text{ft} \times 5\ \text{ft} \times 7.48\ \text{gal/ft}^3}{32\ \text{gpm} \times 60\ \text{min/hr}} = 27\ \text{hr}$$

408. $$\frac{7.7}{3.1} = 2.5$$

$$\frac{7920\ \text{mg/L} \times 0.14\ \text{MGD} \times 8.34\ \text{lb/gal}}{0.785 \times 36\ \text{ft} \times 36\ \text{ft}} = 9.1\ \text{lb/d/ft}^2$$

409.

$$\frac{9.1\ \text{lb/d/ft}^2}{24\ \text{hr/d}} = 0.38\ \text{lb/d/ft}^2$$

410. $\frac{6780 \text{ mg/L}}{7010 \text{ mg/L}} \times 100 = 97\%$

411. $\frac{170 \text{ gpm} \times 1440 \text{ min/d}}{0.785 \times 30 \text{ ft} \times 30 \text{ ft}} = 326 \text{ gpd/ft}^2$

412. $\frac{3.0}{3.3} \times 100 = 91\%$

413. 9 cfm × 60 min/hr × 0.075 lb/$ft^3$ = 41 lb/hr

414. 110 gpm × 1440 min/d × 8.34 lb/gal × (4/100) = 52,842 lb/d

From underflow: 50 gpm × 1440 min/d × 8.34 lb/gal × (7.7/100) = 46,237 lb/d

From effluent flow: (110 gpm – 50 gpm) × 1440 min/d × 8.34 × (0.070/100) = 504 lb/d

In: 52,842 lb/d

Out: 46,237 + 504 = 46,741 lb/d

Because more solids are entering the thickener than leaving, the sludge blanket will increase.

415. $\frac{60 \text{ gpm} \times 1440 \text{ min/d} \times 8.34 \text{ lb} \times (4.1/100)}{0.785 \times 32 \text{ ft} \times 32 \text{ ft}} = 36.7 \text{ lb/d/ft}^2$

416. $\frac{190{,}000 \text{ gpd}}{1440 \text{ min/d}} = 132 \text{ gpm}$

$\frac{132 \text{ gpm}}{60 \text{ ft} \times 40 \text{ ft}} = 0.16 \text{ gpm/ft}^2$

417. $\frac{0.785 \times 26 \text{ ft} \times 26 \text{ ft} \times 2.6 \text{ ft} \times 7.48 \text{ gal/ft}^3 \times 8.34 \text{ lb/gal}}{\frac{9400 \text{ lb/d}}{24 \text{ hr/d}}} = 15.25 \text{ hr}$

418. $\frac{84{,}000 \text{ gpd}}{24 \text{ hr/d}} = 3500 \text{ gph}$

419. $\frac{6 \text{ cfm} \times 0.075 \text{ lb/ft}^3}{110 \text{ gpm} \times 8.34 \text{ lb/gal} \times (0.81/100)} = 0.06$

420. $112 = \frac{x \text{ gpm}}{74 \text{ gpm}} \times 100$

$\frac{112 \times 74}{100} = x$

$x$ = 83 gpm

421. $\frac{79{,}000 \text{ gpd}}{24 \text{ hr/d}} \times \frac{32 \text{ min}}{34 \text{ min}} = 3090 \text{ gal/hr}$

422. $\frac{2.5 \text{ ft}}{6 \text{ ft}} = \frac{x \text{ lb/min stored solids}}{48 \text{ lb/min solids entering}}$

$\frac{2.5 \times 48}{6} = x$

$x$ = 20 lb/min storage rate

48 lb/min = $x$ lb/min + 20 lb/min

$x$ = 28 lb/min solids withdrawal

Sludge withdrawal: $x$ gpm × 8.34 lb/gal × (8/100) = 20 lb/min

$x$ = 41 gpm

423. $$\frac{110{,}000 \text{ gpd} \times 8.34 \text{ lb/gal} \times (0.711/100)}{24 \text{ hr/d}} = 272 \text{ lb/hr}$$

424. $$\frac{34 \text{ ft}^3 \times 7.48 \text{ gal/ft}^3 \times 8.34 \text{ lb/gal} \times (6.6/100)}{70 \text{ gpm} \times 8.34 \text{ lb/gal} \times (0.73/100)} = 32.5 \text{ min}$$

425. $$100 \text{ gpm} \times 60 \text{ min/hr} \times 8.34 \text{ lb/gal} \times (0.79/100) \times \frac{24 \text{ min}}{25.5 \text{ min}} = 372 \text{ lb/hr}$$

426. $$\frac{\left[12 \text{ ft}^3 \times 62.4 \text{ lb/ft}^3 \times (3.9/100)\right] + \left[5 \text{ ft}^3 \times 62.4 \text{ lb/ft}^3 \times (7.8/100)\right]}{\left(12 \text{ ft}^3 \times 62.4 \text{ lb/ft}^3\right) + \left(5 \text{ ft}^3 \times 62.4 \text{ lb/ft}^3\right)} \times 100 =$$

$$\frac{29.2 \text{ lb} + 24.3 \text{ lb}}{749 \text{ lb} + 312 \text{ lb}} \times 100 = 5\%$$

427. $$\frac{\left[4240 \text{ gpd} \times 8.34 \text{ lb/gal} \times (5.9/100)\right] + \left[6810 \text{ gpd} \times 8.34 \text{ lb/gal} \times (3.5/100)\right]}{\left(4120 \text{ gpd} \times 8.34 \text{ lb/gal}\right) + \left(6810 \text{ yd} \times 8.34 \text{ lb/gal}\right)} \times 100 =$$

$$\frac{2086 \text{ lb/d} + 1988 \text{ lb/d}}{34{,}361 \text{ lb/d} + 56{,}795 \text{ lb/d}} \times 100 = 4.5\%$$

428. $$\frac{\left[3510 \text{ gpd} \times 8.34 \text{ lb/gal} \times (5.2/100)\right] + \left[5210 \text{ gpd} \times 8.34 \text{ lb/gal} \times (4.1/100)\right]}{\left(3510 \text{ gpd} \times 8.34 \text{ lb/gal}\right) + \left(5210 \text{ yd} \times 8.34 \text{ lb/gal}\right)} \times 100 =$$

$$\frac{1517 \text{ lb/d} + 1782 \text{ lb/d}}{29{,}273 \text{ lb/d} + 43{,}451 \text{ lb/d}} \times 100 = 4.5\%$$

429. $$\frac{\left[3910 \text{ gpd} \times 8.34 \text{ lb/gal} \times (6.3/100)\right] + \left[6690 \text{ gpd} \times 8.34 \text{ lb/gal} \times (4.9/100)\right]}{\left(3910 \text{ gpd} \times 8.34 \text{ lb/gal}\right) + \left(6690 \text{ yd} \times 8.34 \text{ lb/gal}\right)} \times 100 =$$

$$\frac{2054 \text{ lb/d} + 2734 \text{ lb/d}}{32{,}609 \text{ lb/d} + 55{,}795 \text{ lb/d}} \times 100 = 5.4\%$$

430. $$\frac{\left[2510 \text{ gpd} \times 8.34 \text{ lb/gal} \times (4.3/100)\right] + \left[3600 \text{ gpd} \times 8.34 \text{ lb/gal} \times (6.1/100)\right]}{\left(4120 \text{ gpd} \times 8.34 \text{ lb/gal}\right) + \left(6810 \text{ yd} \times 8.34 \text{ lb/gal}\right)} \times 100 =$$

$$\frac{900 \text{ lb/d} + 1889 \text{ lb/d}}{20{,}993 \text{ lb/d} + 30{,}960 \text{ lb/d}} \times 100 = 5.4\%$$

431. 0.9 gal/stroke × 30 strokes/min = 27 gpm

432. 0.785 × 0.83 ft × 0.83 ft × 0.25 ft × 7.48 gal/ft$^3$ = 1 gal/stroke

1 gal/stroke × 30 strokes/min = 30 gpm

433. 0.785 × 0.67 ft × 0.67 ft × 0.25 ft × 7.48 gal/ft$^3$ = 0.7 gal/stroke

0.7 gal/stroke × 32 strokes/min × 120 min/d = 2688 gpd

434. $0.785 \times 1 \text{ ft} \times 1 \text{ ft} \times 0.33 \text{ ft} \times 7.48 \text{ gal/ft}^3 = 1.9 \text{ gal/stroke}$

$91.9 \text{ gal/stroke} \times 32 \text{ strokes/min} \times 140 \text{ min/d} = 8512 \text{ gpd}$

435. $$\frac{130 \text{ mg/L SS removed} \times 2.5 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.035} = 132 \text{ gpm} \times x \text{ min/d} \times 8.34$$

$$\frac{130 \times 2.5 \times 8.34}{0.035 \times 32 \times 8.34} = x$$

$x = 290 \text{ min/d}$

$$\frac{290 \text{ min/d}}{24 \text{ hr/d}} = 12 \text{ min/hr}$$

436. $$\frac{120 \text{ mg/L SS} \times 1.87 \text{ MGD} \times 8.34 \text{ lb/gal}}{0.036} = 28 \text{ gpm} \times x \text{ min/d} \times 8.34 \text{ lb/d}$$

$$x = \frac{120 \times 1.87 \times 8.34}{0.036 \times 28 \times 8.34} = 204 \text{ min/d}$$

$$\frac{204 \text{ min/d}}{24 \text{ hr/d}} = 8.5 \text{ min/hr}$$

437. $$\frac{124 \text{ mg/L removed} \times 3.48 \text{ MGD} \times 8.34 \text{ lb/gal}}{4.0/100} = 38 \text{ gpm} \times x \text{ min/d} \times 8.34 \text{ lb/d}$$

$$x = \frac{124 \times 3.48 \times 8.34}{0.04 \times 38 \times 8.34} = 284 \text{ min/d}$$

$$\frac{284 \text{ min/d}}{24 \text{ hr/d}} = 11.8 \text{ min/hr}$$

438. $$\frac{130 \text{ mg/L removed} \times 1.5 \text{ MGD} \times 8.34 \text{ lb/gal}}{3.2/100} = 32 \text{ gpm} \times x \text{ min/d} \times 8.34 \text{ lb/d}$$

$$x = \frac{130 \times 1.5 \times 8.34}{0.032 \times 932 \times 8.34} = 191 \text{ min/d}$$

$$\frac{191 \text{ min/d}}{24 \text{ hr/d}} = 8 \text{ min/hr}$$

439. $8620 \text{ lb/d solids} \times (66/100) = 5689 \text{ lb/d VS}$

440. $2810 \text{ lb/d solids} \times (67/100) = 1883 \text{ lb/d VS}$

441. $3720 \text{ gpd sludge} \times 8.34 \text{ lb/gal} \times (5.8/100) \times (70/100) = 1260 \text{ lb/d VS}$

442. $5115 \text{ gpd sludge} \times 8.34 \text{ lb/gal} \times (7/100) \times (67/100) = 2001 \text{ lb/d}$

443. $$25 = \frac{x \text{ gal}}{295{,}200 \text{ gal}} \times 100$$

$x = 295{,}200 \text{ gal} \times (25/100)$

$x = 73{,}800 \text{ gal}$

444. $$21 = \frac{x \text{ gal}}{0.785 \times 40 \text{ ft} \times 40 \text{ ft} \times 24 \text{ ft} \times 7.48 \text{ gal/ft}^3} \times 100$$

$x = 0.785 \times 40 \text{ ft} \times 40 \text{ ft} \times 24 \text{ ft} \times 7.48 \text{ gal/ft}^3 \times (21/100)$

$x = 47{,}350 \text{ gal}$

445. $$x = \frac{62,200 \text{ gal}}{0.785 \times 50 \text{ ft} \times 50 \text{ ft} \times 20 \text{ ft} \times 7.48 \text{ gal/ft}^3} \times 100$$

$x = 21\%$

446. $$20 = \frac{x \text{ gal}}{0.785 \times 40 \text{ ft} \times 40 \text{ ft} \times 18 \text{ ft} \times 7.48 \text{ gal/ft}^3} \times 100$$

$x = 0.785 \times 40 \text{ ft} \times 40 \text{ ft} \times 18 \text{ ft} \times 7.48 \text{ gal/ft}^3 \times (20/100)$

$x = 33{,}822$ gal

447. $$\frac{66,130 \text{ lb/d sludge} \times (5.3/100) \times (70/100)}{120,000 \text{ gal} \times 8.34 \text{ lb} \times (6.3/100) \times (56/100)} = \frac{2379 \text{ lb VS/d}}{35,308 \text{ lb VS}}$$

= 0.07 lb volatile solids added per day per lb volatile solids in digester

448. $$0.06 \text{ lb/d/lb VS} = \frac{x \text{ lb/d VS}}{22,310 \text{ gal} \times 8.34 \text{ lb/gal} \times (6.2/100) \times (55/100)}$$

$0.06 \times 22{,}130 \times 8.34 \text{ lb/gal} \times (6.2/100) \times (55/100) = x$ lb/d

$x = 381$ lb VS/d

449. $$\frac{60,400 \text{ lb/d sludge} \times (5.4/100) \times (67/100)}{96,000 \text{ gal} \times 8.34 \text{ lb/gal} \times (5/100) \times (58/100)} = \frac{2185 \text{ lb VS/d}}{23,219 \text{ lb VS}}$$

= 0.09 lb VS added/d/lb VS in digester

450. $$\frac{0.07 \text{ lb VS added/d}}{\text{lb VS in digester}} = \frac{900 \text{ gpd} \times 8.34 \text{ lb/gal} \times (5.5/100) \times (69/100)}{x \text{ gal} \times 8.34 \text{ lb/gal} \times (8.2/100) \times (52/100)}$$

$$x = \frac{900 \times 8.34 \times 0.055 \times 0.69}{0.07 \times 8.80 \times 0.082 \times 0.52}$$

$x = 10{,}962$ gal seed sludge

451. $$\frac{86,100 \text{ lb/d sludge} \times (5/100) \times (7/100)}{0.785 \times 50 \text{ ft} \times 50 \text{ ft} \times 22 \text{ ft}}$$

$= 0.07 \text{ lb VS/d ft}^3$

452. $$\frac{28,500 \text{ gpd} \times 8.34 \text{ lb/gal} \times (5.5/100) \times (72/100)}{0.785 \times 40 \text{ ft} \times 40 \text{ ft} \times 22 \text{ ft}} =$$

$$\frac{0.347 \text{ lb VS/d}}{\text{ft}^3} \times 1000 =$$

$$\frac{0.347 \text{ lb VS/d}}{1 \text{ ft}^3 \times 1000} = \frac{347 \text{ lb VS/d}}{1000 \text{ ft}^3}$$

453. $$\frac{36,220 \text{ gpd} \times 8.34 \text{ lb/gal} \times (5.6/100) \times (68/100)}{0.785 \times 50 \text{ ft} \times 50 \text{ ft} \times 20 \text{ ft}} =$$

$$\frac{0.293 \text{ lb VS/d}}{1 \text{ ft}^3} \times 1000 = \frac{0.293 \text{ lb/d VS}}{1000 \text{ ft}^3}$$

454. $$\frac{16{,}200 \text{ gpd sludge} \times 8.34 \text{ lb/gal} \times (5.1/100) \times (72/100)}{0.785 \times 50 \text{ ft} \times 50 \text{ ft} \times 18 \text{ ft}} =$$

$$\frac{0.14 \text{ lb/d VS}}{\text{ft}^3} =$$

$$\frac{0.14 \text{ lb/d VS}}{1 \text{ ft}^3} \times 1000 = \frac{140 \text{ lb/d VS}}{1000 \text{ ft}^3}$$

455. $$\frac{116/\text{d VS}}{10 \text{ lb digester sludge}} = \frac{2600 \text{ gpd} \times 8.34 \text{ lb/gal} \times (5.7/100) \times (66/100)}{x \text{ lb digested sludge}}$$

$x$ = 2600 gpd × 8.34 × 0.057 × 0.66 × 10

$x$ = 8158 lb digester sludge

456. $$\frac{1 \text{ lb/d VS}}{10 \text{ lb digester sludge}} = \frac{6300 \text{ gpd} \times 8.34 \text{ lb/gal} \times (5/100) \times (70/100)}{x \text{ lb digested sludge}}$$

$x$ = 6300 × 8.34 × 0.05 × 0.70 × 10

$x$ = 18,390 lb digester sludge

457. $$\frac{1 \text{ lb/d VS}}{10 \text{ lb digester sludge}} = \frac{5200 \text{ gpd} \times 8.34 \text{ lb/gal} \times (6.5/100) \times (67/100)}{x \text{ lb digested sludge}}$$

$x$ = 5200 × 8.34 × 0.065 × 0.67 × 10

$x$ = 18,887 lb digester sludge

458. $$\frac{1 \text{ lb/d VS}}{10 \text{ lb digester sludge}} = \frac{3800 \text{ gpd} \times 8.34 \text{ lb/gal} \times (6/100) \times (72/100)}{x \text{ lb digested sludge}}$$

$x$ = 3800 × 8.34 × 0.06 × 0.72 × 10

$x$ = 13,691 lb digester sludge

459. $$\frac{174 \text{ mg/L}}{2220 \text{ mg/L}} = 0.08$$

460. $$\frac{160 \text{ mg/L}}{2510 \text{ mg/L}} = 0.06$$

461. $$\frac{144 \text{ mg/L}}{2410 \text{ mg/L}} = 0.06$$

462. $$\frac{178 \text{ mg/L}}{2620 \text{ mg/L}} = 0.07$$

463. 2280 mg/L × 0.244 MG × 8.34 lb/gal = 4640 lb lime

464. 2010 mg/L × 0.200 MG × 8.34 lb/gal = 3353 lb lime

465. 2540 mg/L × 0.234 MG × 8.34 lb/gal = 4898 lb lime

466. 2410 mg/L × 0.182 MG × 8.34 lb/gal = 3658 lb lime

467. $$\frac{0.68 - 0.52}{0.68 - (0.68 \times 0.52)} \times 100$$

$$\frac{0.16}{0.3264} \times 100 = 49\% \text{ VS reduction}$$

468. $$\frac{0.70-0.54}{0.70-(0.70\times 0.54)}\times 100$$

$$\frac{0.16}{0.322}\times 100 = 50\%\ \text{VS reduction}$$

469. $$\frac{0.70-0.53}{0.70-(0.70\times 0.53)}\times 100$$

$$\frac{0.17}{0.329}\times 100 = 52\%\ \text{VS reduction}$$

470. $$\frac{0.69-0.54}{0.69-(0.69\times 0.54)}\times 100$$

$$\frac{0.15}{0.3174}\times 100 = 47\%$$

471. $$\frac{3800\ \text{gpd}\times 8.34\ \text{lb/gal}\times(6.3/100)\times(73/100)\times(57/100)}{36{,}500\ \text{ft}^3} = 0.02\ \text{lb VS destroyed/d/ft}^3$$

472. $$\frac{4520\ \text{gpd}\times 8.34\ \text{lb/gal}\times(7/100)\times(69/100)\times(54/100)}{33{,}000\ \text{ft}^3} = 0.03\ \text{lb VS destroyed/d/ft}^3$$

473. $$\frac{2600\ \text{gpd}\times 8.34\ \text{lb/gal}\times(5.6/100)\times(72/100)\times(52/100)}{0.785\times 50\ \text{ft}\times 50\ \text{ft}\times 18\ \text{ft}} = 0.01\ \text{lb VS destroyed/d/ft}^3$$

474. $$\frac{2800\ \text{gpd}\times 8.34\ \text{lb/gal}\times(6.1/100)\times(65/100)\times(56/100)}{0.785\times 40\ \text{ft}\times 40\ \text{ft}\times 17\ \text{ft}} = 0.024\ \text{lb VS destroyed/d/ft}^3$$

$$\frac{0.024\ \text{lb VS destroyed/d}}{1\ \text{ft}^3}\times 1000 = \frac{24\ \text{lb VS destroyed}}{1000\ \text{ft}^3}$$

475. $$\frac{6600\ \text{ft}^3\ \text{gas/d}}{500\ \text{lb VS destroyed/d}} = 13.2\ \text{ft}^3/\text{lb VS destroyed}$$

476. $$\frac{19{,}330\ \text{ft}^3\ \text{gas/d}}{2110\ \text{lb VS destroyed/d}\ (59/100)} = 15.5\ \text{ft}^3/\text{lb VS destroyed}$$

477. $$\frac{8710\ \text{ft}^3\ \text{gas/d}}{582\ \text{lb/d VS destroyed/d}} = 15\ \text{ft}^3/\text{lb VS destroyed}$$

478. $$\frac{26{,}100\ \text{ft}^3\ \text{gas/d}}{3320\ \text{lb VS/d}\times(54/100)} = 14.6\ \text{ft}^3/\text{lb VS destroyed}$$

479. $$\frac{0.785\times 40\ \text{ft}\times 40\ \text{ft}\times 12\ \text{ft}\times 7.48\ \text{gal/ft}^3}{9100\ \text{gpd}} = 12.4\ \text{d}$$

480. $$\frac{0.785\times 40\ \text{ft}\times 40\ \text{ft}\times 10\ \text{ft}\times 7.48\ \text{gal/ft}^3}{8250\ \text{gpd}} = 11.4\ \text{d}$$

481. $$\frac{80\ \text{ft}\times 25\ \text{ft}\times 12\ \text{ft}\times 7.48\ \text{gal/ft}^3}{7800\ \text{gpd}} = 23\ \text{d}$$

482. *3.4% solids:*

$$\frac{0.785 \times 30 \text{ ft} \times 30 \text{ ft} \times 12 \text{ ft} \times 7.48 \text{ gal/ft}^3}{11{,}000 \text{ gpd}} = 5.8 \text{ d}$$

*6% solids:*

$$\frac{0.785 \times 30 \text{ ft} \times 30 \text{ ft} \times 12 \text{ ft} \times 7.48 \text{ gal/ft}^3}{5400 \text{ gpd}} = 11.7 \text{ d}$$

Higher solids content permits greater time for digestion.

483. $$\frac{40 \text{ cfm}}{1000 \text{ ft}^3} = \frac{x \text{ cfm air removed}}{0.785 \times 70 \text{ ft} \times 70 \text{ ft} \times 10 \text{ ft}}$$

$$x = \frac{40 \times 0.785 \times 70 \text{ ft} \times 70 \text{ ft} \times 10 \text{ ft}}{1000} = 1539 \text{ cfm air}$$

$0.06 \times 90 \times 30 \times 12 = x$

$x = 1944$ cfm air

484. $$\frac{40 \text{ cfm}}{1000 \text{ ft}^3} = \frac{x \text{ cfm air removed}}{0.785 \times 70 \text{ ft} \times 70 \text{ ft} \times 10 \text{ ft}}$$

$$x = \frac{40 \times 0.785 \times 70 \text{ ft} \times 70 \text{ ft} \times 10 \text{ ft}}{1000} = 1539 \text{ cfm air}$$

485. $$\text{Oxygen uptake } (\text{mg/L/hr}) = \frac{5.4 \text{ mg/L} - 3.4 \text{ mg/L}}{3 \text{ min}} \times 60 \text{ min/hr}$$

$$\frac{2 \times 60}{3} = 40 \text{ mg/hr}$$

486. $$\text{Oxygen uptake } (\text{mg/L/hr}) = \frac{5.7 \text{ mg/L} - 3.6 \text{ mg/L}}{3 \text{ min}} \times 60 \text{ min/hr}$$

$$\frac{2.1 \times 60}{3} = 42 \text{ mg/L/hr}$$

487. 22 mg/L × 0.106 MG × 8.34 lb/gal = 19.4 lb caustic

488. 16 mg/L × 0.148 MG × 8.34 lb/gal = 19.7 lb caustic

489. $$\frac{64 \text{ mg}}{2 \text{ L}} \times 0.054 \text{ MG} \times 8.34 \text{ lb/gal} = 14.4 \text{ lb caustic}$$

490. 0.785 × 60 ft × 60 ft × 14 ft × 7.48 gal/ft$^3$ = 295,939 gal

$$\frac{90 \text{ mg}}{2 \text{ L}} \times 0.296 \text{ MG} \times 8.34 \text{ lb/gal} = 111 \text{ lb caustic}$$

491. 3.6 gpm × 1440 min/d × 8.34 lb/gal × (5.1/100) × (71/100) = 1566 lb VS/d

492. 0.785 × 55 ft × 55 ft × 22 ft = 52,242 ft$^3$

47,200 gal/d × 8.34 lb/d × (5.3/100) × (71/100) = 14,813 lb VS/d

$$\frac{14{,}813 \text{ lb VS/d}}{52{,}252 \text{ ft}^3} = 0.28 \text{ lb VS ft}^3\text{/d}$$

493. $$\frac{181 \text{ mg/L}}{2120 \text{ mg/L}} = 0.085$$

494. 756,000 L = 0.756 mL

0.756 mL × 1820 mg/L = 1376 kg

495. $\% \text{ VS reduction} = \dfrac{0.67 - 0.55}{0.67 - (0.67 \times 0.55)} \times 100\% = 39.8\%$

496. 2600 kg VS × (100/9.5) × (100/66) × (1L/1.14 kg) =

$$\frac{2600 \times 10.5 \times 1.5}{1.14} = 35{,}921 \text{ L}$$

497. $\dfrac{1 \text{ lb/d VS}}{10 \text{ lb digested sludge}} = \dfrac{8200 \text{ gpd} \times 8.34 \text{ lb/gal} \times (5.7/100) \times (65/100)}{x \text{ lb digested sludge}}$

$x$ = 8200 × 8.34 × 0.057 × 0.65 × 10 = 25,338 lb

498. 4400 lb/d solids × (67/100) = 2948 lb/d VS

499. $\dfrac{12{,}900 \text{ gpd} \times 8.34 \text{ lb/gal} \times (5.4/100) \times (65/100)}{\dfrac{0.785 \times 60 \text{ ft} \times 60 \text{ ft} \times 20 \text{ ft}}{1000}} = \dfrac{67 \text{ lb/d VS}}{1000 \text{ ft}^3}$

500. $\dfrac{[4040 \text{ gpd} \times 8.34 \text{ lb/gal} \times (5.4/100)] + [5820 \text{ gpd} \times 8.34 \text{ lb/gal} \times (3.3/100)]}{(4040 \text{ gpd} \times 8.34 \text{ lb/gal}) + (5820 \text{ gal} \times 8.34 \text{ lb/gal})}$

$$\frac{1819 \text{ lb/d} + 1602 \text{ lb/d}}{33{,}694 \text{ lb/d} + 45{,}339 \text{ lb/d}} \times 100 = 4.3\%$$

501. 0.785 × 0.67 ft × 0.67 ft × 0.5 ft × 7.48 gal/ft$^3$ = 1.3 gal/stroke

1.3 gal/stroke × 3500 strokes/d = 4550 gpd

502. $x = \dfrac{88{,}200 \text{ gal}}{0.785 \times 60 \text{ ft} \times 60 \text{ ft} \times 24 \text{ ft} \times 7.48 \text{ gal/ft}^3} \times 100$

$x$ = 17.4%

503. $\dfrac{3800 \text{ gpd sludge} \times 8.34 \text{ lb/gal} \times (4.1/100) \times (70/100) \times (54/100)}{36{,}000 \text{ ft}^3} =$

0.01 lb/d VS destroyed/ft$^3$

504. $\dfrac{156 \text{ mg/L}}{2310 \text{ mg/L}} = 0.07$

505. 2240 mg/L × 0.24 MG × 8.34 lb/gal = 4484 lb lime

506. $24 = \dfrac{x \text{ gal}}{0.785 \times 50 \text{ ft} \times 50 \text{ ft} \times 22 \text{ ft} \times 7.48 \text{ gal/ft}^3} \times 100 =$

$$\frac{24 \times 0.785 \times 50 \times 50 \times 22 \times 7.48}{100} = 77{,}508 \text{ gal}$$

507. 4310 gpd sludge × 8.34 lb/gal × (5.3/100) × (72/100) = 1372 lb/d VS

508. $\dfrac{[2940 \text{ gpd} \times 8.34 \text{ lb/gal} \times (5.9/100)] + [4720 \text{ gpd} \times 8.34 \text{ lb/gal} \times (3.8/100)]}{(2940 \text{ gpd} \times 8.34 \text{ lb/gal}) + (4720 \text{ gpd} \times 8.34 \text{ lb/gal})} \times 100 =$

$$\frac{1447 \text{ lb/d} + 1496 \text{ lb/d}}{24{,}520 \text{ lb/d} + 39{,}365 \text{ lb/d}} \times 100 = 4.6\%$$

509. $\dfrac{150 \text{ mg/L}}{2470 \text{ mg/L}} = 0.06$

510. $\dfrac{42{,}500 \text{ lb/d sludge} \times (4/100) \times (60/100)}{94{,}000 \text{ gal} \times 8.34 \times (6/100) \times (55/100)} = 0.04 \text{ lb VS added/d lb VS in digester}$

511. $0.785 \times 0.75 \text{ ft} \times 0.75 \text{ ft} \times 0.42 \text{ ft} \times 7.48 \text{ gal/ft}^3 = 1.4 \text{ gal/stroke}$

$1.4 \text{ gal/stroke} \times 30 \text{ strokes/min} = 42 \text{ gpm}$

512. $\dfrac{19{,}200 \text{ gpd} \times 8.34 \text{ lb/gal} \times (5/100) \times (66/100)}{\dfrac{0.785 \times 40 \text{ ft} \times 40 \text{ ft} \times 21 \text{ ft}}{1000}} = \dfrac{200 \text{ lb VS added/d}}{1000 \text{ ft}^3}$

513. $2200 \text{ mg/L} \times 0.3 \text{ MG} \times 8.34 \text{ lb/gal} = 5504 \text{ lb lime}$

514. $\dfrac{6760 \text{ ft}^3}{580 \text{ lb VS destroyed/d}} = 11.7 \text{ ft}^3 \text{ gas lb VS destroyed}$

515. $\dfrac{0.67 - 0.52}{0.67 - (0.67 \times 0.52)} \times 100 = 47\%$

516. $\dfrac{0.09 \text{ lb/d VS added}}{1 \text{ lb VS in digester}} = \dfrac{1230 \text{ gpd} \times 8.34 \text{ lb/gal} \times (4.1/100) \times (66/100)}{x \text{ gal} \times 8.5 \text{ lb/gal} \times (7.5/100) \times (55/100)}$

$x = \dfrac{1230 \times 8.34 \times 0.041 \times 0.66}{0.09 \times 8.5 \times 0.075 \times 0.55}$

$x = 8688 \text{ gal}$

517. $\dfrac{0.70 - 0.56}{0.70 - (0.70 \times 0.56)} \times 100 = 45\%$

518. $\dfrac{0.785 \times 60 \text{ ft} \times 60 \text{ ft} \times 12 \text{ ft} \times 7.48 \text{ gal/ft}^3}{9350 \text{ gpd}} = 27.1 \text{ d}$

519. $\dfrac{22{,}400 \text{ ft}^3 \text{ gal/d}}{2610 \text{ lb VS/d} \times (56/100)} = 15 \text{ ft}^3\text{/lb destroyed}$

520. $\dfrac{3200 \text{ gpd} \times 8.34 \text{ lb/gal} \times (6.4/100) \times (68/100) \times (55/100)}{\dfrac{0.785 \times 50 \text{ ft} \times 50 \text{ ft} \times 22 \text{ ft}}{1000}} = \dfrac{14.8 \text{ lb/d destroyed}}{1000 \text{ ft}^3}$

521. $\dfrac{0.05 \text{ cfm}}{1 \text{ ft}^3 \text{ digester volume}} = \dfrac{x \text{ cfm air required}}{80 \text{ ft} \times 20 \text{ ft} \times 12 \text{ ft}}$

$0.05 \times 80 \text{ ft} \times 20 \text{ ft} \times 12 \text{ ft} = x$

$x = 960 \text{ cfm air}$

522. $22 \text{ mg/L} \times 0.12 \text{ MG} \times 8.34 \text{ lb/gal} = 22 \text{ lb caustic}$

523. $\dfrac{6.0 \text{ mg/L} - 3.8 \text{ mg/L}}{3 \text{ min}} \times 60 \text{ min/hr} = 44 \text{ mg/L/hr}$

524. $\dfrac{119 \text{ mg/L} \times 2.2 \text{ MGD} \times 8.34 \text{ lb/gal}}{(3.0/100)} = 25 \text{ gpm} \times 8.34 \text{ lb/gal} \times x \text{ min/d}$

$\dfrac{122 \times 2.4 \times 8.34}{0.030 \times 25 \times 8.34} = x$

$x = 390 \text{ min/d}$

$$\frac{390 \text{ min/d}}{24 \text{ hr/d}} = 16.3 \text{ min/hr pump operating time}$$

525. 2.6% solids: $\dfrac{0.785 \times 32 \text{ ft} \times 32 \text{ ft} \times 24 \text{ ft} \times 7.48 \text{ gal/ft}^3}{12{,}000 \text{ gpd}} = 12 \text{ d}$

4.6% solids: $\dfrac{0.785 \times 32 \text{ ft} \times 32 \text{ ft} \times 24 \text{ ft} \times 7.48 \text{ gal/ft}^3}{5400 \text{ gpd}} = 27 \text{ d}$

526. $\dfrac{\dfrac{1100 \text{ gal}}{3 \text{ hr}} \times 8.34 \text{ lb/gal} \times (3.8/100)}{140 \text{ ft}^2} = 0.83 \text{ lb/hr/ft}^2$

527. $\dfrac{\dfrac{820 \text{ gal}}{2 \text{ hr}} \times 9.34 \text{ lb/gal} \times (5/100)}{160 \text{ ft}^2} = 1.1 \text{ lb/hr/ft}^2$

528. $0.80 \text{ lb/hr ft}^2 \times \dfrac{2 \text{ hr}}{2 \text{ hr} + 20 \text{ min}} = 0.80 \text{ lb/hr ft}^2 \times \dfrac{2 \text{ hr}}{2.33 \text{ hr}} = 0.7 \text{ lb/hr/ft}^2$

529. $\dfrac{\dfrac{680 \text{ gal}}{2 \text{ hr}} \times 8.34 \text{ lb/gal} \times (3.9/100)}{130 \text{ ft}^2} = 0.85 \text{ lb/hr/ft}^2$

$$0.85 \text{ lb/hr/ft}^2 \times \frac{2 \text{ hr}}{2.33 \text{ hr}} = 0.7 \text{ lb/hr/ft}^2$$

530. $\dfrac{140 \text{ gpm}}{6 \text{ ft}} = 23 \text{ gpm/ft}$

531. $\dfrac{21{,}300 \text{ lb/d}}{12 \text{ hr/d}} = 1775 \text{ lb/hr}$

532. $1800 \text{ lb/hr} = \dfrac{23{,}100 \text{ lb/d}}{x \text{ hr/d operating time}}$

$$x = \frac{23{,}100 \text{ lb/d}}{1800 \text{ lb/h}}$$

$x = 13$ hr/d

533. 160 gpm × 60 min/hr × 8.34 lb/gal × (4.4/100) = 3523 lb/hr

534. 0.7% = 7000 mg/L

$$\frac{4 \text{ gpm} \times 1440 \text{ min/d}}{1{,}000{,}000} = 0.00576 \text{ MGD}$$

$$\frac{7000 \text{ mg/L} \times 0.00576 \text{ MGD} \times 8.34 \text{ lb/gal}}{24 \text{ hr/d}} = 14 \text{ lb/hr}$$

535. $\dfrac{80 \text{ gpm} \times 60 \text{ min/hr} \times 8.34 \text{ lb/gal} \times (5.1/100)}{320 \text{ ft}^2} = 6.4 \text{ lb/hr/ft}^2$

536. $\dfrac{6810 \text{ lb/hr} \times (31/100)}{320 \text{ ft}^2} = 6.6 \text{ lb/hr/ft}^2$

537. $3.3 \text{ lb/hr/ft} = \dfrac{\dfrac{5400 \text{ lb/d}}{x \text{ hr/d operator}}}{230 \text{ ft}^2} \times (90/100)$

$$3.3 \text{ lb/hr/ft}^2 = \frac{5400 \text{ lb/d}}{x \text{ hr/d}} \times 1/230 \text{ ft}^2 \times (90/100)$$

$$x = \frac{5400 \times 1 \times 90}{3.3 \times 230 \times 100} = 6.4 \text{ hr/d operations}$$

538. $\text{Filter yield } (\text{lb/hr/ft}^2) = \dfrac{\dfrac{18{,}310 \text{ lb/d}}{10 \text{ hr/d}}}{265 \text{ ft}^2} \times (91/100) =$

$$\frac{1831 \text{ lb/hr}}{265 \text{ ft}^2} \times 91/100 = 6.3 \text{ lb/hr/ft}^2$$

539. $\dfrac{18{,}400 \text{ lb/hr} \times (20/100)}{85{,}230 \text{ lb/hr} \times (5.9/100)} \times 100 =$

$$\frac{3680 \text{ lb/hr}}{5029 \text{ lb/hr}} \times 100 = 73\% \text{ solids recovery}$$

540. $210 \text{ ft} \times 22 \text{ ft} \times 0.67 \text{ ft} \times 7.48 \text{ gal/ft}^3 = 23{,}154 \text{ gal}$

541. $240 \text{ ft} \times 26 \text{ ft} \times 0.67 \text{ ft} \times 7.48 \text{ gal/ft}^3 = 31{,}272 \text{ gal}$

542. $\dfrac{\dfrac{168{,}000 \text{ lb}}{21 \text{ d}} \times 365 \text{ d/yr} \times (4.6/100)}{190 \text{ ft} \times 20 \text{ ft}} = 35.3 \text{ lb/yr/ft}^2$

543. $220 \text{ ft} \times 30 \text{ ft} \times 0.75 \times 7.48 \text{ gal/ft}^3 \times 8.34 \text{ lb/gal} = 308{,}797 \text{ lb}$

$$\frac{\dfrac{308{,}797 \text{ lb}}{25 \text{ d}} \times 365 \text{ d/yr} \times (39/100)}{220 \text{ ft} \times 30 \text{ ft}} = 26.6 \text{ lb/yr/ft}^2$$

544. $0.785 \times 50 \text{ ft} \times 50 \text{ ft} \times 2.4 \text{ ft} = 4710 \text{ ft}^3$

545. $0.785 \times 50 \text{ ft} \times 50 \text{ ft} \times 1.17 \text{ ft} = 70 \text{ ft} \times 40 \text{ ft} \times x \text{ ft} = 0.82 \text{ ft}$

546. Sludge moisture:

$$\frac{[4700 \text{ lb/d} \times (79/100)] + [3800 \text{ lb/d} \times (26/100)]}{4700 \text{ lb/d} + 3800 \text{ lb/d}} \times 100 =$$

$$\frac{3713 \text{ lb/d} + 988 \text{ lb/d}}{8500 \text{ lb/d}} \times 100 = 55\%$$

547. Sludge moisture = 83%

$$\frac{[4800 \text{ lb/d} \times (83/100)] + [3800 \text{ lb/d} \times (27/100)]}{4800 \text{ lb/d} + x \text{ lb/d}} \times 100$$

$$42/100 = \frac{3984 \text{ lb/d} + x \text{ lb/d}}{4800 \text{ lb/d} + x \text{ lb/d}}$$

$0.42 \times (4800 + x) = 3984 + 0.27x$

$2016 + 0.42x = 3984 + 0.27x$

$0.42x - 0.27x = 3984 - 2016$

$0.15x = 1968$

$x = 13{,}120$ lb/d

548. $$\frac{[7.4 \text{ yd}^3 \text{ sludge} \times 1710 \text{ lb/yd} \times (19/100)] + [7.4 \text{ yd}^3 \times 3 \times 760 \text{ lb/yd}^3 \times (54/100)]}{(7.4 \text{ yd}^3 \text{ sludge} + 1710 \text{ lb/yd}^3) + (7.4 \text{ yd}^3 \times 3 \times 760 \text{ lb/yd}^3)} \times 100 =$$

$$\frac{2404 \text{ lb solids from sludge} + 9111 \text{ lb solids from the wood chips}}{12{,}654 \text{ lb sludge} + 16{,}872 \text{ lb wood chips}} \times 100 =$$

$$\frac{11{,}515 \text{ lb solids}}{29{,}526 \text{ lb compost blend}} \times 100 = 39\% \text{ solids in compost blend}$$

549. $$21 \text{ d} = \frac{8200 \text{ yd}^3}{\dfrac{x \text{ lb/d}}{1000 \text{ lb/yd}^3}}$$

$$21 \text{ d} = \frac{8200 \text{ yd}^3 \times 1000 \text{ lb/yd}^3}{x \text{ lb/d}}$$

$$x \text{ lb/d} = \frac{8200 \text{ yd}^3 \times 1000 \text{ lb/yd}^3}{21 \text{ d}}$$

$x = 390{,}476$ lb/d

550. $$\frac{[12 \text{ yd}^3 \text{ sludge} \times 1720 \text{ lb/yd} \times (16/100)] + [12 \text{ yd}^3 \times 3 \times 820 \text{ lb/yd}^3 \times (55/100)]}{(12 \text{ yd}^3 \text{ sludge} + 1720 \text{ lb/yd}^3) + (12 \text{ yd}^3 \times 3 \times 820 \text{ lb/yd}^3)} \times 100 =$$

$$\frac{3302 \text{ lb solids from sludge} + 16{,}236 \text{ lb solids from the wood chips}}{20{,}640 \text{ lb sludge} + 29{,}520 \text{ lb wood chips}} \times 100 =$$

$$\frac{19{,}538 \text{ lb solids}}{50{,}160 \text{ lb compost blend}} \times 100 = 39\% \text{ solids in compost blend}$$

551. $$21 \text{ day} = \frac{7810 \text{ yd}^3 \times 1100 \text{ lb/yd}^3}{\dfrac{x \text{ lb/d dry solids}}{0.19} + \left(\dfrac{x \text{ lb/d dry solids}}{0.19} \times \dfrac{3 \text{ mix ratio}}{1} \times \dfrac{780 \text{ lb/yd}^3}{1720 \text{ lb/yd}^3}\right)}$$

$$21 = \frac{7{,}810{,}000}{x/0.19 + 7.16x}$$

$$21 = \frac{7{,}810{,}000}{1/0.19x + 7.16x}$$

$$21 = \frac{7{,}810{,}000}{5.26x + 7.16x}$$

$$21 = \frac{7{,}810{,}000}{12.42x}$$

$$12.42x = \frac{7{,}810{,}000}{21}$$

$$x = \frac{7{,}810{,}000}{21 \times 12.42}$$

$x = 29{,}923$ lb/d dry solids

552. (150 gpm) (60 min/hr) (8.34 lb/gal) (4.8/100) = 3603 lb/hr

553. 220 ft × 24 ft × 0.83 × 7.48 gal/ft³ = 32,780 gal

32,780 gal × (3.3/100) × 8.34 lb/gal = 9022 lb

$$\frac{9022 \text{ lb}}{22 \text{ d}} = 410.09 \text{ lb/d}$$

410.09 lb/d × 365 day/yr = 149,683 lb/yr

149,683 lb/yr × (1/220 ft) × 24 ft = 28.3 lb/yr/ft²

554. $$\frac{0.20 \text{ MG/d} \times 1{,}000{,}000 \text{ gal}}{1440 \text{ min/d}} = 139 \text{ gpm}$$

555. 960 gal × (94.2/100) × 8.34 lb/gal = 336.27 lb

$$\frac{336.27 \text{ lb}}{140 \text{ min}} \times 60 \text{ min/hr} = 144 \text{ lb/hr}$$

$$\frac{144 \text{ lb/hr}}{150 \text{ ft}^2} = 0.96 \text{ lb/hr/ft}^2$$

556. Area = 3.14 × 9.6 ft × 10 ft = 301 ft²

36 gpm × 60 min/hr × 8.34 lb/gal × (12/100) = 2162 lb/hr

$$\frac{2162 \text{ lb/hr}}{301 \text{ ft}^2} = 7.2 \text{ lb/hr/ft}^2$$

557. 3020 lb/hr × (40/100) = 1208 lb/hr

24 gal/min × 60 min/hr × 8.50 lb/gal × (11/100) = 1346 lb/hr

$$\% \text{ Recovery} = \frac{1208 \text{ lb/hr}}{1346 \text{ lb/hr}} \times 100 = 90\%$$

558. $$\frac{25{,}200 \text{ lb/d}}{12 \text{ hr/d}} = 2100 \text{ lb/hr}$$

559. $$\frac{800 \text{ gal/2 hr} \times 8.34 \text{ lb/gal} \times (4.1/100)}{141 \text{ ft}^2} = 0.97 \text{ lb/hr/ft}^2$$

560. 170 gpm × 60 min/hr × 8.34 lb/gal × (5/100) = 4253 lb/hr

$$\frac{4253 \text{ lb/hr}}{2000 \text{ lb/ton}} = 2.1 \text{ tons/hr}$$

$$\frac{2.8 \text{ gpm} \times 1440 \text{ min/d}}{1{,}000{,}000} = 0.0040 \text{ MGD}$$

9000 mg/L × 0.0040 MGD × 8.34 lb/gal = 300 lb/d

$$\frac{300 \text{ lb/d}}{24 \text{ hr/d}} = 12.5 \text{ lb/hr flocculant}$$

$$\frac{12.5 \text{ lb/hr}}{2.1 \text{ tons/hr solids}} = 5.95 \text{ lb flocculant/ton solids}$$

561. $$0.8 \text{ lb/hr/ft}^2 \times \frac{2 \text{ hr}}{2 \text{ hr} + 20 \text{ min}} =$$

$$0.8 \text{ lb/hr/ft}^2 \times \frac{2 \text{ hr}}{2.33 \text{ hr}} = 0.69 \text{ lb/hr/ft}^2$$

562. 24,300 mg/L – 740 mg/L = 23,560 mg/L

563. $\dfrac{80 \text{ gpm} \times 60 \text{ min/hr} \times 8.34 \text{ lb/gal} \times (5.5/100)}{320 \text{ ft}^2} = 6.9 \text{ lb/hr/ft}^2$

564. $\dfrac{7500 \text{ lb/hr} \times (26/100)}{320 \text{ ft}^2} = 6.1 \text{ lb/hr/ft}^2$

565. $1800 \text{ lb/hr} = \dfrac{28{,}300 \text{ lb/d}}{x \text{ hr/d}}$

$$x = \frac{28{,}300 \text{ lb/d}}{1800 \text{ lb/hr}} = 15.7 \text{ hr/d}$$

566. $3.1 = \dfrac{\dfrac{5700 \text{ lb/d}}{x \text{ hr/d}}}{280 \text{ ft}^2} \times 92/100$

$$3.1 = \frac{5700 \text{ lb/d}}{x \text{ lb/d}} \times \frac{1}{280 \text{ ft}^2} \times \frac{92}{100}$$

$$x = \frac{5700 \times 1 \times 2}{3.1 \times 280 \times 100} = 6 \text{ hr/d operation}$$

567. $220 \text{ ft} \times 30 \text{ ft} \times 0.75 \text{ in.} \times 7.48 \text{ gal/ft}^3 = 37{,}026 \text{ gal}$

568. $\dfrac{14{,}300 \text{ lb/hr} \times (28/100)}{91{,}000 \text{ lb/hr sludge} \times (5.3/100)} \times 100 =$

$$\frac{4004 \text{ lb/hr}}{4823 \text{ lb/hr}} \times 100 = 83\% \text{ solids recovery}$$

569. 8 in. = 0.67 ft

$200 \text{ ft} \times 25 \text{ ft} \times 0.67 \text{ ft} \times 7.48 \text{ gal/ft}^3 \times 8.34 \text{ lb/gal} = 208{,}984 \text{ lb sludge}$

$$\frac{\dfrac{208{,}984 \text{ lb}}{20 \text{ d}} \times \dfrac{365 \text{ d}}{\text{yr}} \times (5.1/100)}{200 \text{ ft} \times 25 \text{ ft}} = \frac{183{,}070 \text{ lb/yr}}{5000 \text{ ft}^2} = 36.6 \text{ lb/yr/ft}^2$$

570. $\dfrac{0.785 \times 40 \text{ ft} \times 40 \text{ ft} \times 1}{190 \text{ ft} \times 30 \text{ ft}} = x$

$x = 0.22$ ft

571. Moisture content = 75%

$$55 = \frac{[6800 \text{ lb/d} \times (75/100)] + [x \text{ lb/d} \times (36/100)]}{6800 \text{ lb/d} + x \text{ lb/d}} \times 100$$

$$55/100 = \frac{5100 \text{ lb/d} + (x \text{ lb/d} \times 0.36)}{6800 \text{ lb/d} + x \text{ lb/d}}$$

$0.55 \times (6800 \text{ lb/d} + x) = 5100 + 0.36x$

$3740 + 0.55x = 5100 + 0.36x$

$0.55x - 0.36x = 5100 - 3740$

$0.19x = 1360$

$x = 7{,}158$ lb/d compost required

572. $$\frac{[7.0 \text{ yd}^3 \text{ sludge} \times 1710 \text{ lb/yd}^3 \times (16/100)] + [7.0 \text{ yd}^3 \times 3 \times 780 \text{ lb/yd}^3 \times (51/100)]}{(7.0 \text{ yd}^3 \text{ sludge} + 1710 \text{ lb/yd}^3) + (7.0 \text{ yd}^3 \times 3 \times 780 \text{ lb/yd}^3)} \times 100$$

$$\frac{1915 \text{ lb solids from the sludge} + 8354 \text{ lb solids from the wood chips}}{11{,}970 \text{ lb sludge} + 16{,}380 \text{ lb wood chips}} \times 100$$

$$\frac{10{,}269 \text{ lb solids}}{28{,}350 \text{ lb compost blend}} \times 100 = 36.2\% \text{ solids in compost blend}$$

573. $$26 \text{ d} = \frac{6350 \text{ yd}^3}{\dfrac{x \text{ lb/d}}{980 \text{ lb/ft}^3}}$$

$$26 \text{ d} = \frac{6350 \text{ yd}^3 \times 980 \text{ lb/yd}^3}{x \text{ lb/d}}$$

$$x = \frac{6350 \text{ yd}^3 \times 980 \text{ lb/yd}^3}{26 \text{ d}}$$

$x$ = 239,346 lb/d

$$\frac{239{,}346 \text{ lb/d}}{2000 \text{ lb/ton}} = 120 \text{ tons/d}$$

574. $$24 \text{ d} = \frac{9000 \text{ yd}^3 \times 1100 \text{ lb/yd}^3}{\dfrac{x \text{ lb/d dry solids}}{0.18} + \left(\dfrac{x \text{ lb/d dry solids}}{0.18} \times \dfrac{3.3 \text{ mix ratio}}{1} \times \dfrac{800 \text{ lb/yd}^3}{1710 \text{ lb/yd}^3}\right)}$$

$$24 = \frac{9{,}900{,}000}{(1/0.18)x + 8.58x}$$

$$24 = \frac{9{,}900{,}000}{5.56x + 8.58x}$$

$$24 = \frac{9{,}900{,}000}{14.14x}$$

$$14.14x = \frac{9{,}900{,}000}{24}$$

$$x = \frac{9{,}900{,}000}{24 \times 14.14}$$

$x$ = 29,204 lb/d dry solids

## LABORATORY CALCULATIONS (WATER AND WASTEWATER) (PROBLEMS 1 TO 80)

1. $$\frac{66 \text{ sec}}{60 \text{ sec/min}} = 1.1 \text{ min}$$

$$\frac{1 \text{ gal}}{1.1 \text{ min}} = 0.9 \text{ gpm}$$

2. $$\frac{58\text{ sec}}{60\text{ sec/min}} = 0.9\text{ min}$$

$$\frac{1\text{ gal}}{0.9\text{ min}} = 1.1\text{ gpm}$$

3. $$\frac{22\text{ sec}}{60\text{ sec/min}} = 0.37 = 1.37\text{ min}$$

$$\frac{1\text{ gal}}{1.37\text{ min}} = 0.73\text{ gpm}$$

4. 0.7 gpm = (1 gal/$x$ min)
$x$ = (1/0.7)
$x$ = 1.4 min
1.4 min × 60 sec/min = 84 sec

5. $$0.6\text{ gpm} = \frac{1\text{ gal}}{x\text{ min}}$$
$x$ = 1/0.6 = 1.67 min
1.67 min × 60 sec/min = 100 sec

6. $$\frac{0.75\text{ in.}}{12\text{ in./ft}} = 0.06\text{ ft}$$

$$\text{Flushing time (min)} = \frac{0.785 \times 0.06\text{ ft} \times 0.06\text{ ft} \times 32\text{ ft} \times 7.48\text{ gal/ft}^3 \times 2}{0.5\text{ gpm}} = 2.7\text{ min}$$

7. 3/4–in. pipe = 0.06-ft diameter

$$\text{Flushing time (min)} = \frac{0.785 \times 0.06\text{ ft} \times 0.06\text{ ft} \times 28\text{ ft} \times 7.48\text{ gal/ft}^3 \times 2}{0.6\text{ gpm}} = 2.0\text{ min}$$

8. 3/4–in. pipe = 0.06-ft diameter

$$\text{Flushing time (min)} = \frac{0.785 \times 0.06\text{ ft} \times 0.06\text{ ft} \times 36\text{ ft} \times 7.48\text{ gal/ft}^3 \times 2}{0.5\text{ gpm}} = 3\text{ min}$$

9. 0.5 in./12 in./ft = 0.04 ft

$$\text{Flushing time (min)} = \frac{0.785 \times 0.04\text{ ft} \times 0.04\text{ ft} \times 22\text{ ft} \times 7.48\text{ gal/ft}^3 \times 2}{0.5\text{ gpm}}$$

= 0.8 min = 0.8 min × 60 sec/min = 48 sec
= 0.8 min × 60 sec/min = 48 sec

10. $$\frac{2.4\text{ equivalents}}{2\text{ L}} = 1.2\,N$$

11. $$\frac{800\text{ mL}}{1000\text{ mL}} = 0.8\text{ L} =$$

$$\frac{1.4\text{ equivalents}}{0.8\text{ L}} = 1.75\,N$$

12. 0.5 × $x$ mL = 0.02 × 500 mL

$$x = \frac{0.02 \times 0.05\text{ mL}}{0.5}$$

$x$ = 20 mL NaOH

13. $$\frac{6\text{ g}}{1000\text{ mL}} = \frac{4.88\text{ g}}{x\text{ mL}}$$

$6 \times x = 4.88 \times 1000$

$$x = \frac{4.88 \times 1000}{6}$$

$x = 813$ mL

14. $$\frac{100\text{ mg}}{100\text{ mL}} = \frac{98.16\text{ mg}}{x\text{ mL}}$$

$100 \times x = 98.16 \times 100$

$$x = \frac{98.16 \times 100}{100}$$

$x = 98.16$ mL

15. $$\frac{100\text{ g}}{1000\text{ mL}} = \frac{94.28\text{ g}}{x\text{ mL}}$$

$100 \times x = 94.28 \times 1000$

$$x = \frac{94.28 \times 1000}{100}$$

$x = 943$ mL

16. $$\frac{2.6\text{ equivalents}}{1.9\text{ L}} = 1.4\,N$$

17. $$\frac{320\text{ mL}}{1000\text{ mL}} = 0.32\text{ L} =$$

$$\frac{1.5\text{ equivalents}}{0.32\text{ L}} = 4.69\,N$$

18. $0.6 \times x$ mL $= 0.05 \times 780$ mL

$$x = \frac{0.05 \times 780\text{ mL}}{0.6}$$

$x = 65$ mL NaOH

19. $$\frac{8\text{ mg/L} - 3.7\text{ mg/L}}{\frac{7\text{ mL}}{350\text{ mL}}} = 215\text{ mg/L BOD}$$

20. $$\frac{8.3\text{ mg/L} - 4.4\text{ mg/L}}{\frac{12\text{ mL}}{320\text{ mL}}} = 104\text{ mg/L BOD}$$

21. $$\frac{1401}{7} = 200\text{ mg/L}$$

22. 7-day average for June 10: June 10 + 6 previous day = 1484/7 = 212 mg/L
7–day average for June 11: June 11 + 6 previous day = 1492/7 = 213 mg/L
7-day average for June 12: June 12 + 6 previous day = 1484/7 = 212 mg/L

23. $$\frac{440\text{ mL}}{2000\text{ mL}} \times 100 = 22\%$$

24. $$\frac{320\text{ mL}}{2000\text{ mL}} \times 100 = 16\%$$

25. $\dfrac{410 \text{ mL}}{2000 \text{ mL}} \times 100 = 20.5\%$

26. $\dfrac{2.9 \text{ moles}}{0.8 \text{ L}} = 3.6\ M$

27. $1.7 \text{ M} = \dfrac{x \text{ moles}}{0.9 \text{ L}}$

$x = 1.53$ moles

28. $\dfrac{28 \text{ g}}{40 \text{ g/mole}} = 0.7 \text{ moles}$

29. $\dfrac{0.5 \text{ moles}}{1.8 \text{ L}} = 0.28\ M$

30. 

| **Total Sample (g)** | **Total Solids (g)** | **Volatile Solids (g)** |
|---|---|---|
| 85.78 | 26.27 | 24.31 |
| –21.50 | –21.50 | –21.50 |
| 64.28 | 4.77 | 2.81 |

(a) $\text{Total solids } (\%) = \dfrac{4.77 \text{ grams total solids}}{61.75 \text{ grams sludge}} \times 100$

$= 7.7\%$ total solids

(b) $\text{Volatile solids } (\%) = \dfrac{2.81 \text{ grams volatile solids}}{4.77 \text{ grams total solids}}$

$= 59\%$ volatile solids

31. 

| **Sludge (Total Sample) (g)** | **Total Solids (g)** | **Volatile Solids (g)** |
|---|---|---|
| 75.48 | 22.67 | 21.45 |
| –20.80 | –20.80 | –20.80 |
| 54.68 | 1.87 | 0.65 |

(a) $\text{Total solids } (\%) = \dfrac{1.87 \text{ grams total solids}}{54.68 \text{ grams sludge}} \times 100$

$= 3.4\%$ total solids

(b) $\text{Volatile solids } (\%) = \dfrac{0.65 \text{ gram volatile solids}}{1.87 \text{ grams total solids}} \times 100 = 35\%$

32. 

| **Total Solids (g)** | **Volatile Solids (g)** |
|---|---|
| 22.0188 | 22.0090 |
| –22.0022 | –22.0022 |
| 0.0166 | 0.0068 |

(a) $\text{Volatile solids } (\%) = \dfrac{0.0068 \text{ volatile solids}}{0.0166 \text{ total solids}} \times 100 = 41\%$

(b) $\dfrac{0.068 \text{ g VS}}{100 \text{ mL}} \times \dfrac{1000 \text{ mg}}{1 \text{ g}} = \dfrac{6.8 \text{ mg VS} \times 10}{100 \text{ mL} \times 10} = 68 \text{ mg/L VS}$

33. Total solids

(a)
$$\begin{array}{r} 25.6818\text{ g} \\ -25.6715\text{ g} \\ \hline 0.0103\text{ g} \end{array}$$

$$\frac{0.0103\text{ g}}{50\text{ mL}} \times \frac{1000\text{ mg}}{1\text{ g}} \times \frac{20}{20} = 206\text{ mg/L SS}$$

(b)
$$\begin{array}{r} 25.6802\text{ g} \\ -25.6715\text{ g} \\ \hline 0.0087\text{ g} \end{array}$$

$$\%\text{ VSS} = \frac{0.0087}{0.0103} \times 100 = 84\%\text{ VSS}$$

34. (a) Grams SS

$$\begin{array}{r} 36.1588\text{ g} \\ -36.1496\text{ g} \\ \hline 0.0092\text{ g} \end{array}$$

$$\frac{0.0092\text{ g}}{25\text{ mL}} \times \frac{1000\text{ mg}}{1\text{ g}} \times \frac{40}{40} = 368\text{ mg/L SS}$$

(b) Grams VSS

$$\begin{array}{r} 36.1543\text{ g} \\ -36.1496\text{ g} \\ \hline 0.0047\text{ g VSS} \end{array}$$

$$\%\text{ VSS} = \frac{0.0047\text{ g}}{0.0092\text{ g}} \times 100 = 51\%\text{ VSS}$$

35. Grams SS

(b)
$$\begin{array}{r} 28.3196\text{ g} \\ -28.2981\text{ g} \\ \hline 0.0215\text{ g} \end{array}$$

$$\frac{0.0215\text{ g}}{25\text{ mL}} \times \frac{1000\text{ mg}}{1\text{ g}} \times \frac{40}{40} = 860\text{ mg/L SS}$$

(b) Grams VSS

$$\begin{array}{r} 28.3082\text{ g} \\ -28.2981\text{ g} \\ \hline 0.0101\text{ g} \end{array}$$

$$\%\text{ VSS} = \frac{0.0101\text{ g}}{0.0215\text{ g}} \times 100 = 47\%\text{ VSS}$$

36. $$\frac{220\text{ mL}}{2210\text{ mg/L}} \textit{ or } \frac{220\text{ mL}}{2.21\text{ g}} = 99.5\text{ SVI}$$

37. 205 mL for 1 L

$$\frac{205\text{ mL}}{2310\text{ mg/L}} \textit{ or } \frac{205\text{ mL}}{2.31\text{ g}} = 88.7\text{ SVI}$$

38. $$\frac{2210\text{ mL}}{222\text{ mg}} \times 100 = \frac{2.11\text{ mL}}{222\text{ g}} \times 100 = 0.95\text{ SDI}$$

39. $\frac{2140 \text{ mL}}{186 \text{ mg}} \times 100 = \frac{2.14 \text{ mL}}{186 \text{ g}} \times 100 = 1.15 \text{ SDI}$

40. $\frac{215 \text{ mL}}{2510 \text{ mg/L}}$ *or* $\frac{215 \text{ mL}}{2.51 \text{ g}} = 86 \text{ SVI}$

41. $70^\circ\text{F} + 40^\circ = 110^\circ$
$5/9 \times 110^\circ = 61^\circ$
$61^\circ - 40^\circ = 21^\circ\text{C}$

42. $60^\circ + 40^\circ = 100^\circ$
$5/9 \times 100^\circ = 56^\circ$
$56^\circ - 40^\circ = 16^\circ\text{C}$

43. $24^\circ\text{C} + 40^\circ = 75^\circ\text{F}$
$9/5 \times 64^\circ = 115^\circ$
$115^\circ - 40^\circ = 75^\circ\text{F}$

44. $16^\circ\text{C} + 40^\circ = 56$
$9/5 \times 56^\circ = 101^\circ$
$101^\circ - 40^\circ = 61^\circ\text{F}$

45. $\frac{0.5 \text{ mg/L} \times 10 \text{ mL}}{2 \text{ drops} \times 0.05 \text{ mL/drop}} = 50 \text{ mg/L}$

46. $\frac{0.2 \text{ mg/L} \times 10 \text{ mL}}{3 \text{ drops} \times 0.05 \text{ mL/drop}} = 13 \text{ mg/L}$

47. $\frac{0.3 \text{ mg/L} \times 10 \text{ mL}}{3 \text{ drops} \times 0.05 \text{ mL/drop}} = 20 \text{ mg/L}$

48. $\frac{0.785 \times 0.06 \text{ ft} \times 0.06 \text{ ft} \times 60 \text{ ft} \times 7.48 \text{ gal/ft}^3 \times 2}{0.80 \text{ gpm}} = 3.2 \text{ min}$

49. $\frac{45 \text{ seconds}}{60 \text{ sec/min}} = 0.75 \text{ min}$

$\frac{1 \text{ gal}}{0.75 \text{ min}} = 1.3 \text{ gpm}$

50. $\frac{2.3 \text{ equivalents}}{1.4 \text{ liters}} = 1.6\,N$

51. $\frac{10 \text{ seconds}}{60 \text{ sec/min}} = 0.16 \text{ min} = 1.16 \text{ min}$

$\frac{1 \text{ gal}}{1.16 \text{ min}} = 0.9 \text{ gpm}$

52. $\frac{0.4 \text{ mg/L} \times 10 \text{ mL}}{2 \text{ drops} \times 0.05 \text{ mL/drop}} = 40 \text{ mg/L}$

53. $\frac{0.75 \text{ inches}}{12 \text{ inches/ft}} = 0.06 \text{ ft}$

$\frac{0.785 \times 0.06 \text{ ft} \times 0.06 \text{ ft} \times 75 \text{ ft} \times 7.48 \text{ gal/ft}^3 \times 2}{0.5 \text{ gpm}} = 6.3 \text{ min}$

54. $\frac{55 \text{ grams}}{1000 \text{ mL}} = \frac{45.82 \text{ grams}}{x \text{ mL}}$

$x \times 55 = 45.82 \times 1000$

$x = \frac{45.82 \times 1000}{55}$

$x = 833$ mL

55. $0.8 \text{ gpm} = \frac{1 \text{ gal}}{x \text{ min}}$

$x \times 0.8 = 1$

$x = \frac{1}{0.8} = 1.25$ min

56. $\frac{780 \text{ mL}}{1000 \text{ mL}} = 0.78 \text{ L}$

$\frac{1.3 \text{ equivalents}}{0.78 \text{ L}} = 1.7\,N$

57. $\frac{0.3 \text{ mg/L} \times 10 \text{ mL}}{3 \text{ drops} \times 0.05 \text{ mL/drops}} = 20 \text{ mg/L}$

58. $$\begin{array}{r} 73°\text{F} \\ +40° \\ \hline 113° \end{array}$$

$5/9 \times 113° = 63°$

$$\begin{array}{r} 63° \\ -40° \\ \hline 23° \end{array}$$

$73°\text{F} = 23°\text{C}$

59. $\frac{0.785 \times 0.06 \text{ ft} \times 0.06 \text{ ft} \times 60 \text{ ft} \times 7.48 \text{ gal/cu ft} \times 2}{0.5 \text{ gpm}} = 5.1$ minutes

$= 0.1 \text{ min} \times 60 \text{ sec/minute} = 6$ seconds

$= 5$ minutes 6 seconds

60. $0.2 \times x \text{ mL} = 0.01 \times 500$ mL

$x = \frac{0.01 \times 500 \text{ mL}}{0.2}$

61. $\frac{0.3 \text{ mg/L} \times 10 \text{ mL}}{4 \text{ drops} \times 0.05 \text{ mL/drop}} = 15 \text{ mg/L}$

62. $\frac{7.7112 \text{ g}}{1000 \text{ mL}} = \frac{7.3132 \text{ g}}{x \text{ mL}}$

$x \times 7.7112 = 7.3132 \times 1000$

$x = \frac{7.3132 \times 1000}{7.7112}$

$x = 948$ mL

63. $$\begin{array}{r} 16°\text{C} \\ +40° \\ \hline 56° \end{array}$$

$9/5 \times (56°/1) = 101°$

$$\begin{array}{r} 101° \\ -40° \\ \hline 61° \end{array}$$

16°C = 61°F

64. $$\begin{array}{r} 78° \\ +40° \\ \hline 118° \end{array}$$

$5/9 \times (118°/1) = 66°$

$$\begin{array}{r} 66° \\ -40° \\ \hline 26° \end{array}$$

78°F = 26°C

65. $$\frac{7.12 \text{ mg/L} - 4.37 \text{ mg/L}}{0.06} =$$

$$\frac{2.75}{0.06} = 45.8 = 46 \text{ mg/L}$$

66. (7.28 mg/L – 4.18 mg/L) × (300 mL/10 mL) = 93 mg/L

67. (7.31 mg/L – 4.58 mg/L) – [(7.61 mg/L – 4.87 mg/L) × (0.5%/4%)]

3.03 – (2.74 × 0.5/4) = 2.69 mg/L

2.69 mg/L ÷ 0.17 = 16 mg/L

68. 0.05 $N$ × 2000 mL = 9 $N$ × volume 2

$$\frac{0.05\,N}{9\,N} \times 2000 \text{ mL} = 9\,N/9\,N \times \text{volume 2}$$

$$\frac{0.05\,N}{9\,N} \times 2000 \text{ mL} = \text{volume 2}$$

= 11 mL

69. 4 $N$ × 10 mL = normality 2 × 8.2 mL

$$\frac{4\,N \times 10 \text{ mL}}{8.2 \text{ mL}} = \text{normality 2}$$

= 4.88 $N$

70. $$\frac{15.2 \text{ mL/L}}{16 \text{ mL/L}} \times 100 = 95\% \text{ removed}$$

71. $$\frac{0.80 \text{ moles}}{1.4 \text{ liters}} = 0.57\ M$$

72. $$\frac{310 \text{ mL}}{2000 \text{ mL}} \times 100 = 15.5\% \text{ settled solids}$$

73. $\dfrac{2.3 \text{ equivalents}}{1.30 \text{ liters}} = 1.8\,N$

74. $\dfrac{7.8 \text{ mg/L} - 4.4 \text{ mg/L}}{\dfrac{6 \text{ mL}}{320 \text{ mL}}}$

= [3.4 mg/L × (320 ÷ 6)] = 181 mg/L BOD

75. (a) **Total Solids (g)** **Sludge Sample (g)**

| Total Solids (g) | Sludge Sample (g) |
|---|---|
| 27.80 | 80.28 |
| <u>–25.30</u> | <u>–25.409</u> |
| 2.5 g TS | 54.88 g sludge |

Total solids (%) = $\dfrac{2.5 \text{ g}}{54.88 \text{ g}} \times 100$ = 4.6% total solids

(b) **Volatile Solids (g)**

27.80
<u>–26.18</u>
1.62 g VS

Volatile solids (%) = $\dfrac{1.62 \text{ g}}{2.5 \text{ g}} \times 100$ = 65% volatile solids

76. $\dfrac{222 \text{ mL}}{2.34 \text{ g}} = 95 \text{ SVI}$

77. 75°F + 40° = 115°
5/9 × 115° = 64°
64° – 40° = 24°C

78. $\dfrac{2210 \text{ mg}}{188 \text{ mL}} \times 100 = \dfrac{2.21 \text{ g}}{188 \text{ mL}} \times 100 = 1.18$

79. 17°C + 40° = 57°C
9/5 × 57° = 103°
103° – 40 = 63°F

80. $\dfrac{300 \text{ mL}}{2000 \text{ mL}} \times 100 = 15\%$ settleable solids